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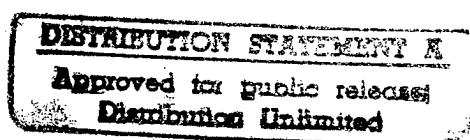
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***Central Eurasia: Engineering &  
Equipment***

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URANIUM RAW MATERIAL BASE

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SCIENCE & TECHNOLOGY  
CENTRAL EURASIA: ENGINEERING & EQUIPMENT  
URANIUM RAW MATERIAL BASE

937F0037A Moscow SYRYEVAYA BAZA URANA SSSR in Russian No 26-29 Aug, 1991  
pp 1-71

[Cover-to-cover translation of the report SYRYEVAYA BAZA URANA SSSR (USSR Uranium Raw Material Base) of the Soviet Delegation to the IAEA Technical Committee (N. P. Laverov, V. I. Velichkin, V. I. Vetrov, V. V. Krotkov, A. L. Lapin, S. S. Naumov, M. D. Pelmenev, and M. V. Shumilin) on 16-29 August 1991, USSR Academy of Sciences, USSR Ministry of Atomic Energy and Industry, and USSR Ministry of Geology, Moscow, 1991]

CONTENTS

USSR Uranium Raw Material Base.....	1
1. Creation and Development of the Uranium Raw Material Base in the USSR.....	1
2. Main Uranium Ore and Prospective Uranium-Bearing Regions of the USSR.....	3
3. Commercial-Genetic Types of Uranium Deposits.....	27
4. Selected Spatiotemporal Laws of the Distribution of Uranium Deposits and Resources Within the Territory of the USSR.....	44

**USSR Uranium Raw Material Base**

937F0037A Moscow SYREVAYA BAZA URANA SSSR in Russian No 26-29 Aug 91 pp 1-71

[Cover-to-cover translation of the report *Syrevaya baza uran SSSR* (USSR Uranium Raw Material Base) of the Soviet Delegation to the IAEA Technical Committee (N.P. Laverov, V.I. Velichkin, V.I. Vetrov, V.V. Krotkov, A.L. Lapin, S.S. Naumov, M.D. Pelmenev, and M.V. Shumilin) on 16-29 August 1991, USSR Academy of Sciences, USSR Ministry of Atomic Energy and Industry, and USSR Ministry of Geology, Moscow, 1991]

**[Text] 1. Creation and Development of the Uranium Raw Material Base in the USSR**

The history of the creation of a uranium raw material base in the USSR is closely tied to the name of one of the most eminent scholars of the 20th century, V.I. Vernadskiy, who back in 1912 indicated the need to study "...the properties and reserves of Russia's radioactive materials." At V.I. Vernadskiy's initiative, a number of expeditions were organized over the course of the period 1914 through 1949. As a result of these expeditions, the Tyuya-Muyun deposit in Fergana was discovered along with the Taboshar (1925), Adrasman (1934), and Maylis (1940) deposits. The discovery of these deposits made it possible to identify the first uranium ore region in the USSR -- the Karamazarskiy region.

Wide-scale systematic searches for uranium deposits in the USSR, as throughout the world, began after the Second World War. During the period before 1950, the uranium deposits of the Krivoy Rog (Pervomayskoye and Zheltovodskoye) and Stavropol (Beshtau and Bykogorskoye) uranium ore regions were discovered along with new deposits in the Karamazarskiy region (Kattasay, Alatanga, Chauli, Maylisay, etc.).

These initial years included not only the foundation of the uranium raw material base but also establishment of the Soviet school of geologist-uranium specialists, which would later develop under conditions of virtual isolation from world practice and develop its own ideas by way of the examples of deposits that are very different from those known in other countries. The possibility of creating a uranium recovery industry at domestic types of deposits was substantiated, original scientific concepts of uranium ore formation were developed, and radiometric equipment was mass-produced.

In the next decade (1950-1960), the development of uranium explorations was based above all on the extensive use of aeroradiometric studies that led to the discovery of a number of new uranium ore regions: the Caspean region (the Melovoye, Tomakskoye, Taybagarskoye, and Tasmurun), Balkhash (Kurday, Bota-Burum, Kyzylsay, Dzhideli), Kyzyl Kum (Uchkuduk), and Kokchetav regions (Manybay, Ishim, Zaozernoye). These discoveries laid the foundation for the creation of a strong uranium recovery industry in the USSR.

In the sixties and seventies, the information accumulated regarding the geology of uranium ore deposits and ore formation models developed by Soviet geological science permitted the efficient discovery of new uranium deposits in closed regions that are inaccessible for study by the aeroradiometry method. One of the most important discoveries of those years was the discovery of the Strelitsa uranium ore region with large deposits of rich ores classified as vein-stockwork uranium deposits in continental volcanic systems. With the discovery of this region, the type of deposit under consideration, which is widely represented almost exclusively in the territory of the USSR, entered the ranks of those types playing a marked role in the world uranium resource balance.

Another important discovery was the discovery of new, larger deposits that were in direct proximity to the known Krivoy Rog region but located in an entirely different geological situation forming the unique Kirovgrad uranium ore region (Michurinskoye, Vatutinskoye, Severinskoye). This type of deposit, which is related to the process of alkaline metasomatism (albitization) was determined to be yet another unique type of uranium deposit that is prevalent mainly in the USSR, i.e., interlaced vein-metasomatic deposits in albitites.

During those same years, the efforts of Soviet scientists and engineers resulted in the creation of methods of working uranium deposits by underground leaching through well systems and in the introduction of these methods into actual practice. These methods made it possible to solve the problem of assimilating uranium deposits lying in friable inundated rock. The corresponding orientation of exploratory work made it possible to quickly discover a number of new deposits in the Kyzyl Kum region, which moved the region in first place in the country with respect to uranium reserves.

In the seventies and eighties several new types of uranium deposits were discovered in the Soviet Union, including stratiform infiltration deposits on paleopeneplain surfaces (the Transural and Vitim regions) and in black shales (in the Kyzyl Kum and in the Onega region). The raw material potential of these types of deposits cannot yet be considered fully determined.

The facilities of the mining and processing systems developed in parallel with the uranium raw material base. The following large enterprises constitute the production potential of the uranium recovery industry of the USSR in its current stage: the Eastern Ore Enrichment Combine (in Zheltyye Vody), the Caspean Mining and Smelting Combine (in Shevchenko), the Navoy Mining and Smelting Combine (in Navoy), the Eastern Rare Metals Combine (in Khodzhent), the Mining and Chemical Combine (in Stepnogorsk), the Yuzhpolimetall Production Association in Bishkek, and the Priargunsk Mining and Chemical

Combine (in Krasnokamensk). These enterprises are included in the USSR Ministry of the Nuclear Power Industry system.

The existing raw material reserve has enabled all of the existing enterprises to operate for a lengthy period.

In this report uranium reserves and resources are presented in accordance with the classification system adopted by the IAEA. Reserves conforming to the existing USSR classification categories B, C<sub>1</sub> and C<sub>2</sub> are classified as proved reserves, those conforming to the category P<sub>1</sub> are classified as additional reserves, and those conforming to the category P<sub>2</sub> are classified as forecast reserves.

The reserves are also classified with respect to the cost of obtaining 1 kg of uranium in concentrate as follows: under \$80/kg, \$80-\$130/kg, and over \$130/kg.\*

## 2. Main Uranium Ore and Prospective Uranium-Bearing Regions of the USSR

At present nine main uranium ore and five prospective uranium-bearing regions have been identified within the territory of the USSR.

Included among the main uranium ore regions are regions of concentrated deposits that either are being worked or that have been worked previously. Most of these regions also contain deposits that have not yet been worked.

Regions where known deposits have not yet been worked and are considered reserve deposits are classified as prospective uranium-bearing regions. All of these regions and the deposits included in them are characterized by a lower level of geological study, and the estimate of the raw material potential of these regions presented is more cautious.

The extensive territory of the Soviet North and Far East remain only slightly studied with respect to uranium. The only uranium deposit in this territory that may, on the basis of its parameters, be considered commercial has been established in the southern portion of the Far East. Findings of uranium mineral deposits that have not been subjected to detailed study are known in many regions, however, from the Polar Ural region to Chukotka and the Ussuriysk Kray. Geological data make it possible to believe that new uranium-bearing regions may be discovered in this enormous territory and that the overall prospects of uranium recovery in the USSR are not limited to the reserves and resources of the known regions.

Figure 1 gives an overall diagram of the location of known uranium ore and uranium-bearing regions within the territory of the USSR.

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\*Here and henceforth, the value of the dollar in relation to the ruble at the end of the seventies and end of the eighties is used (\$100 being approximately equal to 100 rubles at the commercial rate of the USSR State Bank).

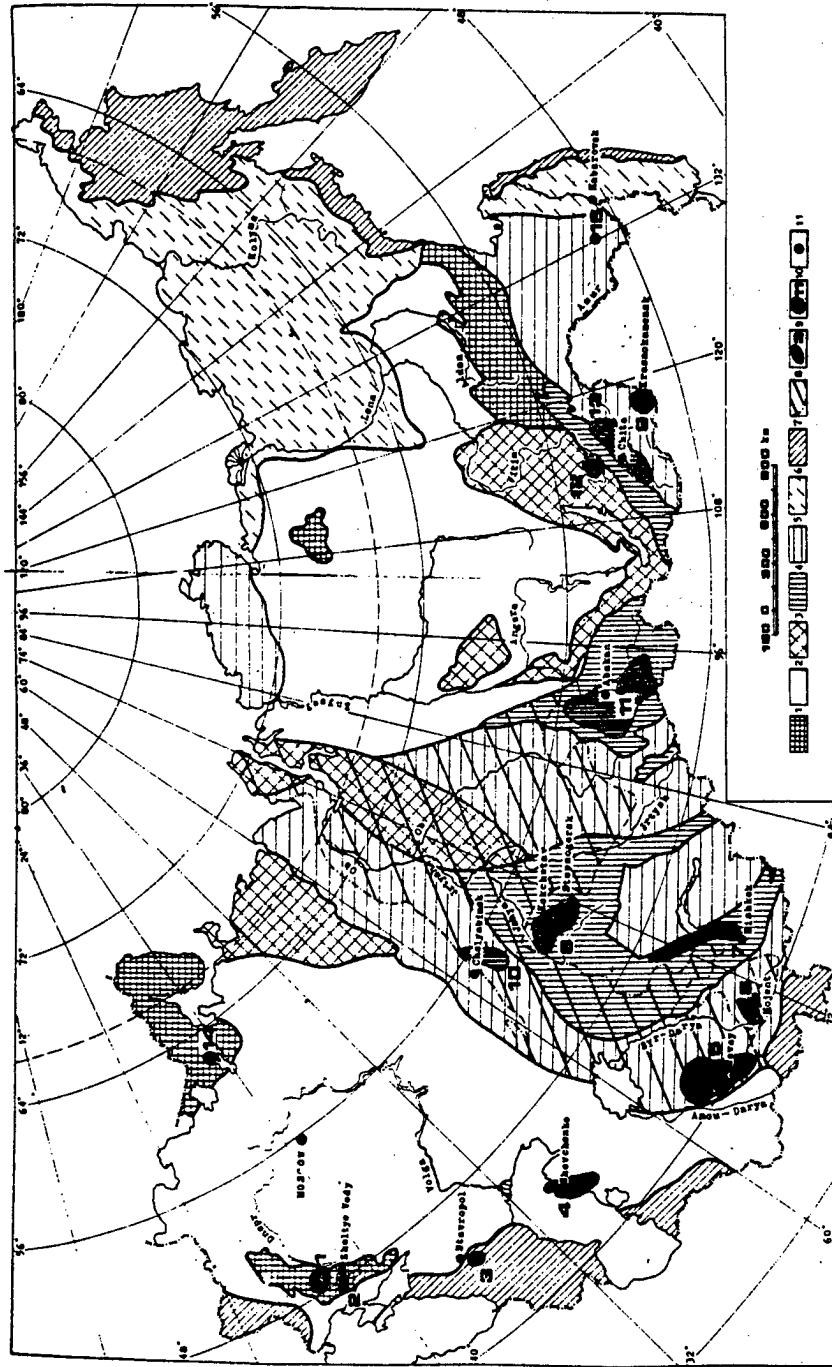


Figure 1. Map of the uranium ore regions of the USSR. Patterns 1 through 8 represent elements of geological structure: 1, systems of the foundation of ancient platforms; 2, systems of the cover of ancient platforms; 3 through 7, geosynclinal-fold systems with varying degrees of stabilization: 3, Baikal; 4, Caledonian; 5, Hercynian; 6, Mesozoic; 7, Cenozoic; 8, systems of the cover of young platforms on the pre-Mesozoic fold basement; 9, uranium ore regions (1, Kirovograd; 2, Krivoy Rog; 3, Stavropol; 4, Caspian; 5, Kyzyl Kum; 6, Karamazarskiy; 7, Balkhash; 8, Kokchetav; 9, Strelitsa; 10, uranium-bearing regions (10, Transural; 11, Yenisey; 12, Vitim; 13, Central Transbaikalia; 14, Omega); II, lone deposits (15, Lastochka).

The concise characteristics of the individual regions are presented below in the historical sequence of their discovery.

The *Karamazarskiy uranium ore region* is located in the northwestern portion of the Tyan Shan [also Tien Shan] mountain system. Its territory encompasses the Chatkal and Kuraminsk mountain ridges and the adjacent part of the Fergana Valley. On the southern border of the region is the city of Hodjent [Khodzhent], the location of the Eastern Rare Metals Combine, which processes uranium ore. The region is an agrarian-industrial region with a well-developed industrial infrastructure.

The Karamazarskiy uranium ore region coincides territorially with the Chatkal-Kuraminsk geoanticlinal uplift and the northern part of the adjacent Fergana ravine, which are located within the confines of the heterogeneous Hercynian fold region of the Ural-Mongolian moving belt. The fold basement of the Chatkal-Kuraminsk uplift, which consists of pre-Paleozoic crystalline and early-middle Paleozoic carbonate-terrigenous rock, is in large part covered with orogenic formations of volcanic origin of the Carboniferous-Permian age or else cut by synchronous multiphase granitoids. Orogenic vulcanites with an andesite-dacite-liparite composition make up the volcanotectonic structures forming the Beltau-Kuraminsk continental volcanoplutonic belt. The Fergana ravine is filled with platform sea sediments of the Mesozoic and Paleogene periods, as well as with coarsely fragmental deposits of Neogenic-Quaternary age.

The uranium deposits of the Karamazarskiy region represent two morphogenetic types: hydrothermal vein-stockwork deposits associated in time and space with the formation of orogenic volcanic structures and stratiform sheet-infiltration deposits in the carbonate rock of the platform cover that are rich in reducing agents of the petroleum series (Figure 2).

Hydrothermal deposits (Alatanga, Kattasay, Chauli, Maylikatan, Charkasar, Taboshar) formed in the Permian period and are controlled by annular, interlayer, and intersecting faults of volcanic structures made of acidic rock, as well as by disjunctives developed in the underlying fold basement. The ore of these deposits are pitchblende-sulfide ores with molybdenum (Alatanga, Chauli); copper, lead, and zinc (Maylikatan, Taboshar); and bismuth (Adrasman). The uranium content varies from hundredths to tenths of a percent.

The sheet-infiltration uranium deposits (Maylisu, Shakaptar, Maylisay) were formed in the Miocene period and are confined to water-and-gas-bearing carbonate horizons of the Paleogene period located in the wings of eroded anticlinals in the edge portion of the Fergana ravine. The ores of these deposits are relatively poor.

The total uranium resources of the deposits of the Karamazarskiy region amounted to 20,000 metric tons. These reserves are now practically completely mined out. The largest reserves were the Alatanga and Chauli deposits (4,500 metric tons each).

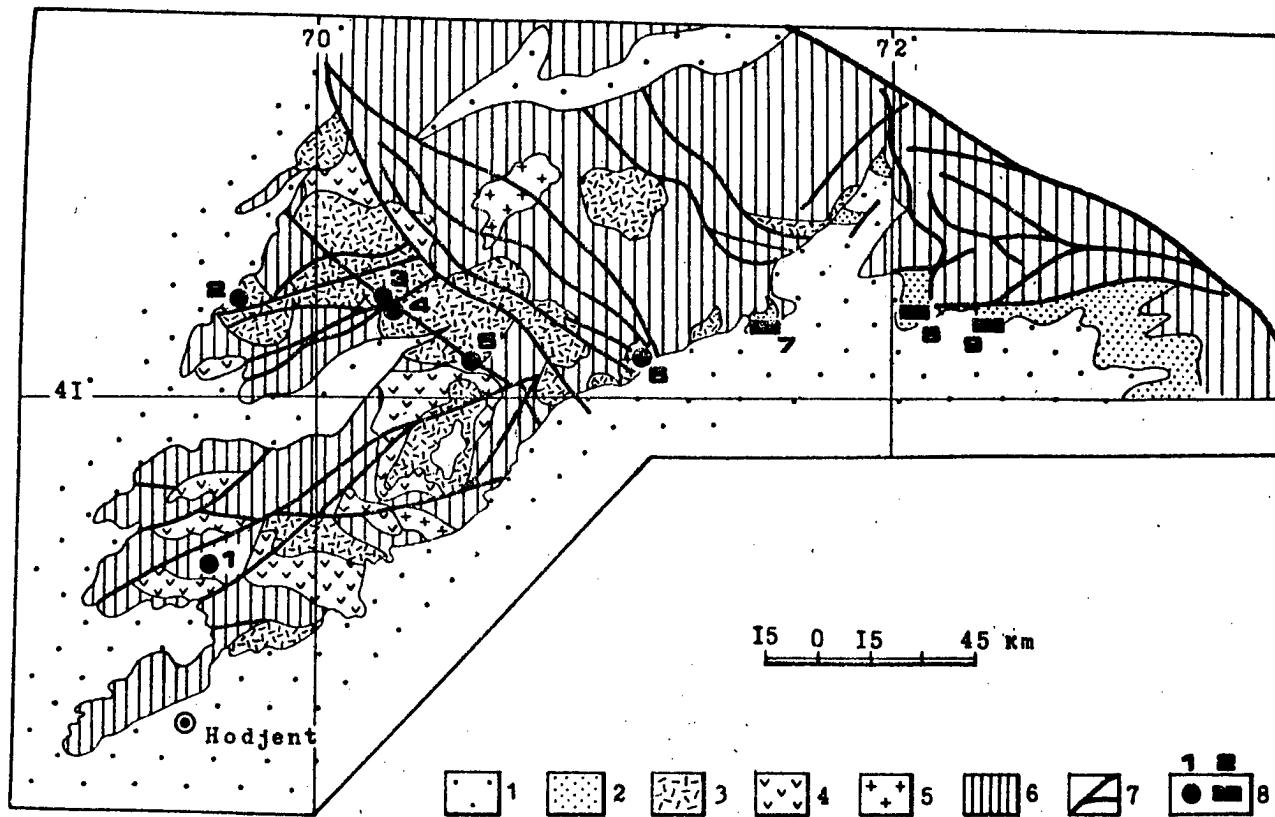


Figure 2. Geological map of the Karamazarskiy uranium ore region: 1-2, platform system (Carboniferous-Quaternary); 1, terrigenous deposits; 2, carbonate-terrigenous deposits (Carboniferous-Permian); 3-4, orogenic system (Caledonian-Permian); 3, late orogenic vulcanites medium-acidic composition; 4, early orogenic vulcanites with a medium-basic composition; 5-6, preorogenic system (Paleozoic); 5, granites; 6, fold formations; 7, faults; 8, uranium deposits of the endogenic series (1, Taboshar, 2, Chauli; 3, Alatanga; 4, Kattasay; 5, Maylikatan; and 6, Charkasar); 9, uranium deposits of the exogenous series (7, Shakaptar; 8, Maylisu; 9, Maylisay).

The *Stavropol uranium ore region* is located in the northern foothills of the Caucasus in the upper part of the Kuma River. The region is economically developed and has a well-developed industry.

The region's geological position is dictated by its position in the edge portion of the ancient Eastern European platform in the zone where it joins with the Alpine fold region of the Caucasus. The region represents an uplift in the crystalline basement of the platform that is overlaid with a cover and bounded and crossed by a system of faults. In the stage of its activation in the late Miocene, magmatic melts became embedded in the sedimentary cover along the fault zones. Subvolcanic laccolith and stocklike intrusive bodies of granite-porphries, granosyenite-porphries, and quartz syenites formed in the process.

Uranium mineralization of the vein-stockwork type is connected both spatially and temporally with the specified intrusive formations and is localized in the xenolite bituminous rock of the cover in the apical portion of the magmatic bodies of the granite-porphyrries. The deposit's sulfide-pitchblende ores have been subjected to intensive supergene transformation and have been completely oxidized to a significant depth.

Two main deposits are known in the region, i.e., the Beshtau and Bykogorskoye deposits, which have total reserves of about 5,000 metric tons of uranium. The deposits have now been completely worked. The specifics of their geological position evidently excludes the possibility that new deposits will be discovered.

The Caucasus region is characterized by finds of uranium mineralization in other geological circumstances, including siderite-pitchblende veins of the mountain ore type in connection with pre-Mesozoic granites, uranium-bitumen mineralization in basal layers of Jurassic deposits, etc. The insignificant scales of these high mountain regions and their inaccessibility makes it difficult to consider them real forecast resources, however.

The *Krivoy Rog uranium ore region* is located on the right bank of the undercurrent of the Dnepr River. The city of Zheltyye Vody is located in the center of the region. It is the home of the Eastern Ore Enrichment Combine, which processes the uranium ores of the Krivoy Rog and adjacent Kirovograd ore regions. The Krivoy Rog region is one of the largest mining regions of the USSR.

The geological position of the Krivoy Rog uranium ore region is dictated by its position on the crystalline shield-ledge of the basement of the ancient Eastern European platform. The region corresponds to a narrow (3 to 9 km) geosynclinal trough with a submeridional direction that divides blocks of early Archean and late Archean stabilizations. The trough is made of intensively folded rock of the Lower Proterozoic Period including conglomerates, crystalline shales, and ferrous quartzites (Figure 3).

The basic uranium deposits of the region (Pervomayskoye and Zheltovodskoye) are localized in shales and ferrous quartzites, are controlled by fold and fault structures, and are associated with zones of intensive alkaline metasomatism (albitization). The ore is 1.8 billion years old. The ores of the deposits have a complex uraninite-brannerite composition and contain phosphorus, zirconium, and scandium impurities. The latter is partially extracted during processing. The superimposition of uranium ore formation processes on early deposits of rich iron ores was noted in the individual sections. These types of ferrous uranium ores have now all been mined out, however.

Surface -infiltration deposits (Devladovskoye, Bratskoye, Surskoye, Safonovskoye, etc.) have been discovered in the early Quaternary deposits of the platform cover within the region's territory. The ores of these deposits are poor, but a portion of them have been mined by the method of underground leaching.

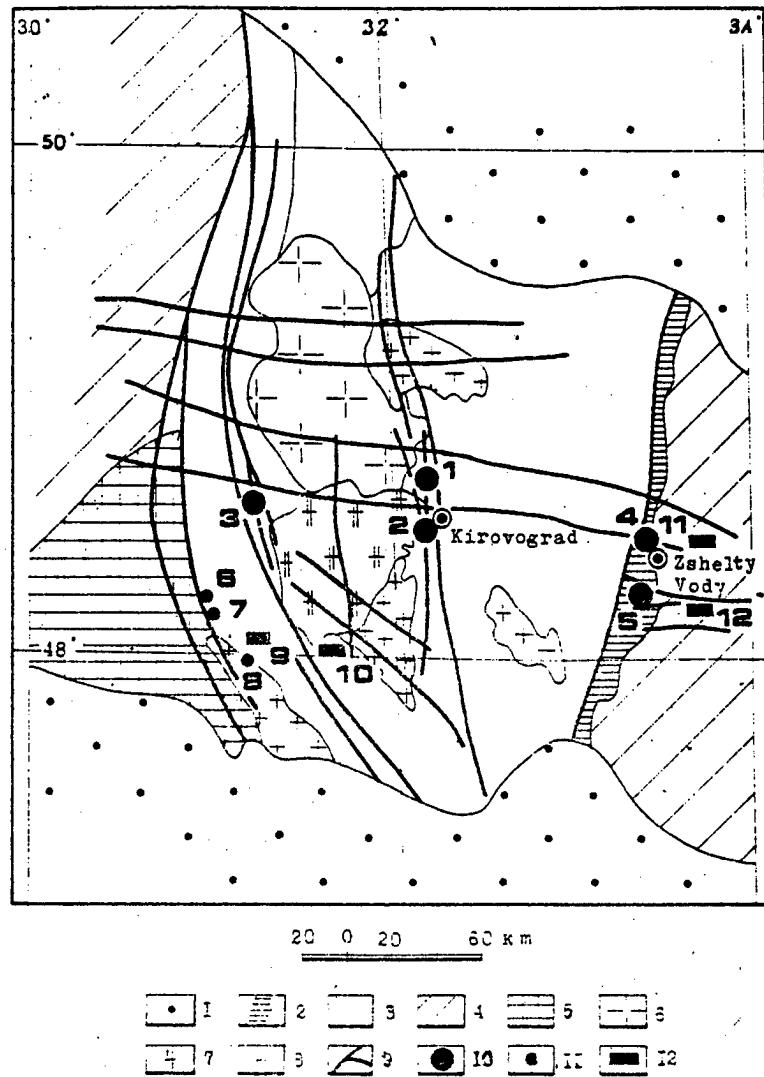


Figure 3. Geological map with the cover of the Neogenic-Quaternary deposits removed. The Kirovograd and Krivoy Rog uranium ore regions: 1, platform system (Carboniferous-Permian); 2-5, metamorphic systems (Archean-Proterozoic): 2, protogeosynclinal (Proterozoic); 3, gneissose granite of early Archean stabilization; 4, gneissic of late Archean stabilization; 5, granulitic (Archean); 6-8, protoorogenic granitoids (Proterozoic): 6, rapakivi granites; 7, granites; 8, subalkaline granites; 9, faults; 10-11, uranium deposits of the endogenic series; 10, in soda metasomatites-albitites (1, Severinskoye; 2, Michurinskoye; 3, Vatutinskoye; 4, Zheltovodskoye; 5, Pervomayskoye); 11, in potassium metasomatites (6, Kalinovskoye; 7, Lozovatskoye; 8, Yuzhnaya); 12, uranium deposits of the exogenic series (9, Sadovoye; 10, Bratskoye; 11, Novoguryevskoye; 12, Devladovo).

There was a total of 35,900 metric tons of uranium resources in the region. These resources have now been largely depleted.

The *Balkhash uranium ore region* occupies an area along the northwestern offshoots of the Tyan Shan mountain system that reaches the western end of

Lake Balkhash and moves farther on to the northwest. The region is rather well developed economically. The Yuzhpolimetall Production Association, which is involved in processing the region's uranium ore, lies close to the city of Bishkek.

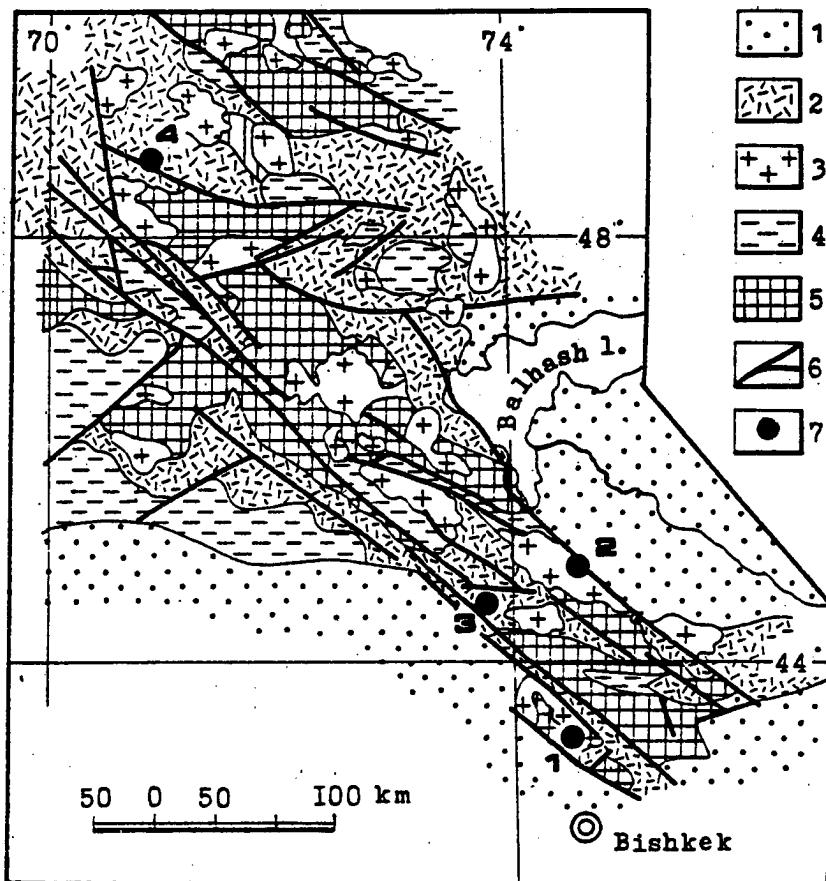


Figure 4. Geological map of the Balkhash uranium ore region: 1, platform system (Mesozoic-Quaternary); 2-3, orogenic system (Paleozoic): 2, acidic vulcanites; 3, granites; 4-5, preorogenic systems: 4, fold volcanogenic-terrigenous (Paleozoic); 5, metamorphic (Proterozoic?); 6, faults; 7, uranium deposits of the endogenic series (1, Kurday; 2, Bota-Burum; 3, Kyzylsay; 4, Dzhideli).

The region's geological position corresponds to the Chuili-Kendyktaskiy geoanticlinal uplift, which is a fragment of the large central mass of the Ural-Mongolian fold belt.

The structure of the above uplift includes gneiss and shales of the pre-Paleozoic basement and continental volcanic systems (from basalts to liparites) of the late Silurian-Devonian period. These systems form a series of volcanotectonic structures controlled by zones of deep faults and separated by ledges of the basement cut by granitoids that are comagmatic with vulcanites.

The region's uranium deposits are classified as vein-stockwork hydrothermal deposits. They are closely related to volcanic systems of liparite

composition from both spatial and formation time standpoints. The region's main deposits (Botaburum, Kzylsay, Kurday, Dzhideli) are similar from a geological standpoint. The Kurday deposit is localized in granites but is structurally linked to the volcanic neck. Other deposits are localized directly in the volcanic apparatus (Figure 4).

The position of the ore bodies is dictated by the combination of tectonic cracks and contacts of volcanic lithofacies.

The ores are classified as being of the uranium-molybdenum type. Their uranium content ranges from 0.1% to 0.3%. Uniquely rich ores (containing more than 10% uranium) have been noted only in the Dzhideli deposit in individual blocks. Ammonium paramolybdate is obtained as a by-product when the ores are processed.

The Botaburum deposit is the largest (10,000 metric tons). The additional and forecast resources of the region are linked both with the probability that new hydrothermal deposits will be discovered and with the possibility that sheet-infiltration deposits will be discovered in the contiguous blocks covered with a Mesozoic-Cenozoic sedimentary cover. These resources total 100,000 metric tons in the under-\$80/kg production cost category.

The *Caspean uranium ore region* is located on the eastern shore of the Caspean Sea on the Mangyshlak Peninsula. The city of Shevchenko is located in the center of the region. It is the home of the Caspean Mining and Smelting Combine, which processes the ores of the region's deposits.

From a geological standpoint, the region represents a young platform whose basement is made up of folded sedimentary systems of Permian-Triassic and Jurassic sediments and whose cover is made up of Cretaceous-Paleogenetic-Neogenic sediments.

The region's uranium mineralization is associated with the sediments of the cover and represents a unique type of deposit -- accumulations of uranium-bearing phosphatized osseous detritus of fossil fish in pyrite-bearing clays (Figure 5).

The deposits' ores of this type have a low uranium content (0.03% to 0.05%); however, osseous detritus is easily separated by rinsing. The uranium content in detritus concentrate is two- to threefold higher, and the content of phosphoric anhydride reaches 30%. Besides uranium and phosphorus, the detritus contains rare earth elements and scandiums that can also be extracted during processing.

The Melovoye deposit is the largest (43,800 metric tons). The reserves of the remaining deposits range from 4,000 to 9,000 metric tons. Accumulations of uranium-bearing osseous detritus in the specified horizon of Paleogenetic deposits are noted both south of the region and on the western shore of the Caspean. Throughout the remaining territory, however, the productive horizon lies at depths excluding the possibility of its economically justified recovery. The prospects of this unique type of deposit are thus limited to the proved reserves of the region's known deposits (64,400 metric tons total).

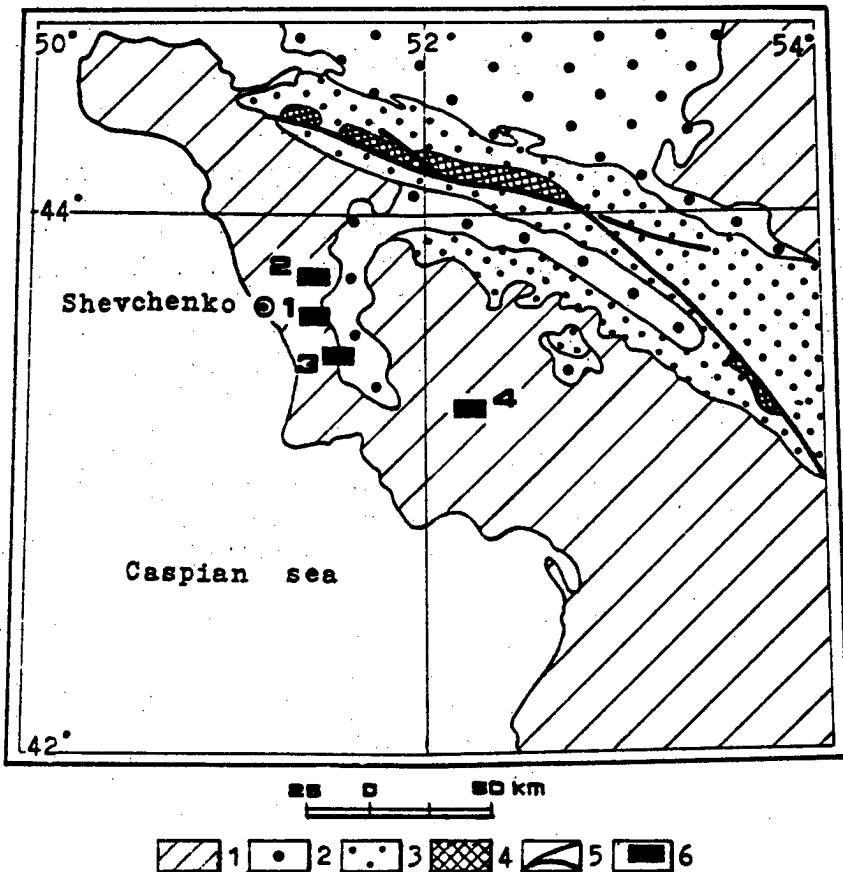


Figure 5. Geological map of the Caspian uranium ore region: 1-3: platform system (Carboniferous-Quaternary): 1, Neogenic-Quaternary sediments; 2, Paleogenic sediments; 3, Cretaceous sediments; 4, fold system (Turonian-Jurassic); 5, faults; 6, uranium deposits of the exogenous series (1, Melovoye; 2, Tomakskoye; 3, Tasmurun; 4, Taybagar).

The *Kokchetav uranium ore region* is located in the extreme southern part of the Western Siberia plain and occupies the interfluvial area of the central current of the Irtysh River and its left tributary the Ishim River. Located in the central part of the region is the city of Kokchetav, and located in the eastern portion is the city of Stepnogorsk, which is where the Tselinnyy Mining and Chemical Combine (which processes the uranium ores of the region's deposits) is located.

The region is an agrarian-industrial region with a well-developed economic infrastructure.

From a geological standpoint, the Kokchetav uranium ore region conforms to the Kokchetav central mass, which is one of the segments of the Kokchetav-Northern Tyan Shan Paleozoic fold arc that is in turn a part of the Ural-Mongolian fold belt.

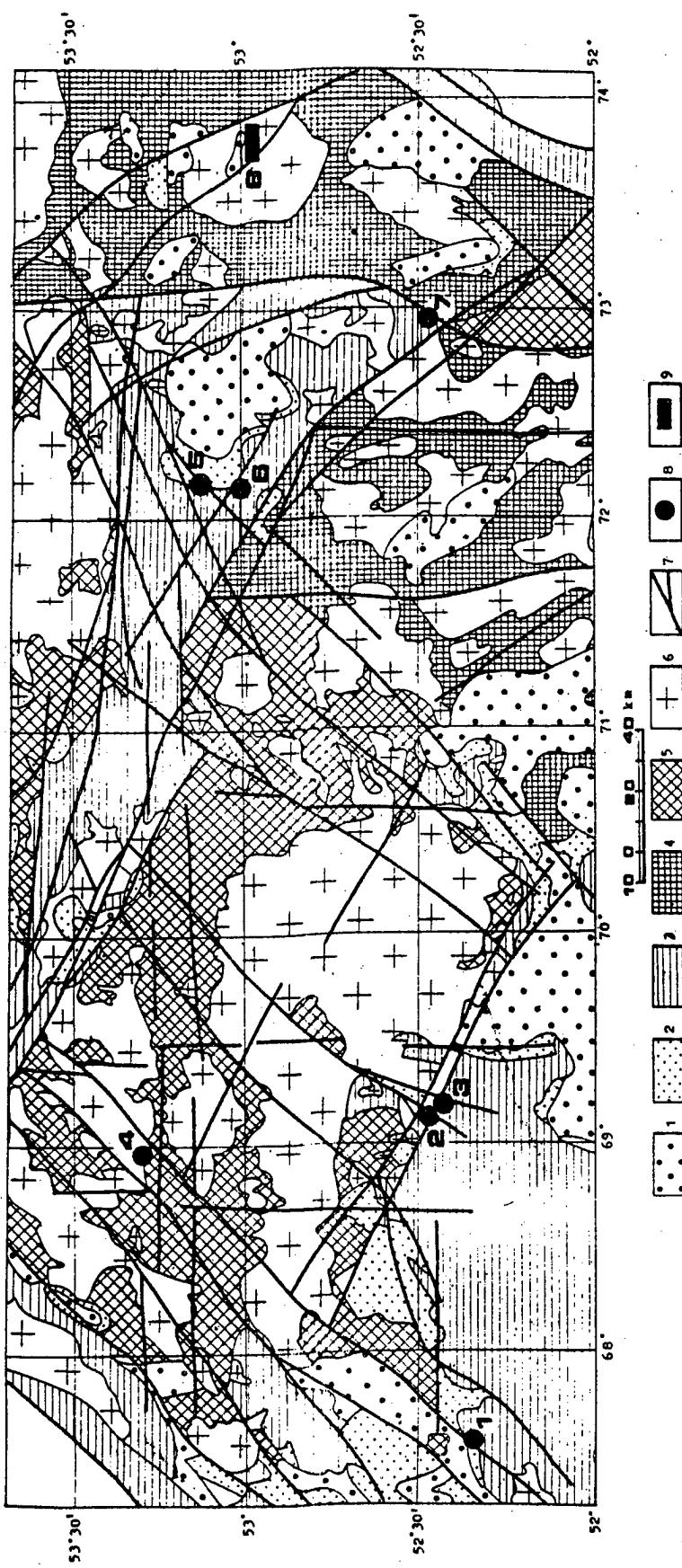


Figure 6. Geological map of the Kokchetav uranium ore region: 1, platform system (Devonian-Cenozoic); 2, orogenic system (Silurian-Devonian); 3, preogenetic system (Eocene-Oligocene); 4, preogenetic system of reduced thickness on a metamorphic basement (Eocene-Oligocene); 5, system of the preogenetic system on a metamorphic basement (Proterozoic); 6, granitoids of the preogenetic system; 7, faults; 8, uranium deposits of the endogenetic series (1, Isimskoye, 2, Vostok; 3, Balkashinskoye; 4, Grachevskoye; 5, Zaozernoye; 6, Tastykolskoye; 7, Manybay); 9, uranium deposits of the exogenetic series (8, Semizbay).

The Kokchetav central mass was formed in the Caledonian epoch. Its fold basement consists of Precambrian crystalline gneiss and weakly metamorphosed vulcanoterrigenous rock of the Cambrian-Ordovician period cut through by multiphase systems of granitoids of Silurian-Devonian age. The individual recesses in the fold basement are made of Silurian-Devonian volcanogenic-sedimentary orogenic and Post-Devonian (Carboniferous-Jurassic) platform sediments.

The mass' fold basement is cut by deep faults that are oriented in different directions and that control the region's main uranium deposits. Two types of deposits are developed in the region: vein-stockwork hydrothermal deposits formed in the epoch of Silurian-Devonian orogenesis and stratiform infiltration-ground deposits associated with the paleovalleys of the Pre-Upper Jurassic peneplain that are buried under the Cretaceous-Cenozoic platform cover (Figure 6).

The vein-stockwork deposits gravitate primarily toward the peripheral part of the central granite-gneiss core of the central mass. Sites containing uranium-molybdenum (Ishimskoye, Vostok, Balkashinskoye, Manybayskoye) and uranium-phosphorous types of ores (Zaozernoye, Tastykolskoye) have been identified among them. Ammonium paramolybdate or phosphorus fertilizers are by-products of the processing of both types of ores at the Tselinnyy Combine.

The stratiform deposits (Samizbay) gravitate toward the extreme northeastern part of the mass.

All of the region's deposits are characterized by relatively poor ores. Large (Vostok, Manybay, Grachevskoye, Zaozernoye, and Semizbay) deposits of about 20,000 metric tons each have been identified as reserves, as have relatively small deposits (Balkashinskoye, Tastykolskoye, etc.) of 1,000 to 3,000 metric tons.

The total uranium reserves in the region amount to 208,000 metric tons, including 99,200 metric tons of proved reserves. Seventy-three percent of the proved reserves are in the under-\$80/kg production cost category. The forecast resources (70,000 metric tons) all fit in the \$80-\$130/kg category.

The Ishimskoye, Balkashinskoye, and Manybayskoye deposits have already been mined out, and the Grachevskoye, Zaozernoye, and Vostok deposits are now being worked.

The *Kyzyl Kum* uranium ore region is located in the interfluvial area of the Amu Darya and Sydarya and occupies that part of the Kyzyl Kum desert plain that is made up of the Bukan-Tau, Tammdy-Tau, Nura-Tau, etc., mountain masses, which are the extreme northwestern offshoots of the Tyan-Shan-Pamir mountain system.

The city of Navoi is located in the southern part of the region. The Navoy Mining and Smelting Combine, which processes the recovery enterprises' uranium product, is located there. The region is rather well assimilated economically and has a well-developed economic infrastructure.

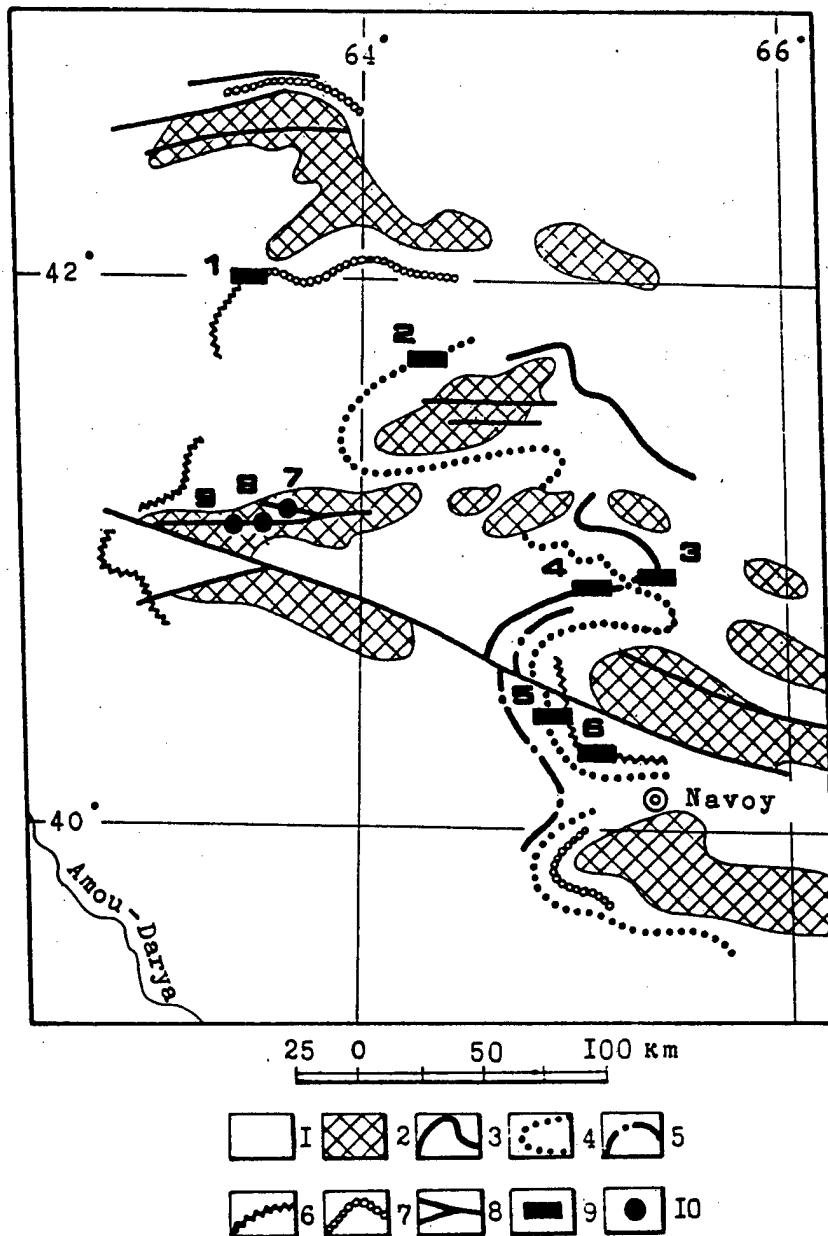


Figure 7. Geological map of the Kyzyl Kum uranium ore region: 1, platform system (Carboniferous-Quaternary); 2, fold system (Paleozoic); 3 through 7, fronts of stratal oxidation in different horizons of the platform system: 3, Paleogene; 4, Cognac-Santonian; 5, Campanian-Maastricht; 6, Upper Turonian; 7, Lower Turonian; 8, faults; 9, uranium deposits of the exogenic series: (1, Uchkuduk; 2, Sugraly; 3, Lyavlyakan; 4, Beshkak; 5, Bukinay; 6, Kanimekh); 10, uranium deposits of the polygenic series: (7, Rudnoye; 8, Koscheka; and 9, Dzhantuar).

From a geological standpoint, the region represents a block of a young epi-Hercynian platform transformed by Alpine tectogenesis. The region is connected to a system of raised and lowered blocks by numerous faults in the

northwestern and sublatitudinal directions. The folded pre-Mesozoic basement is brought out to the surface in the cores of the raised blocks. The lowered blocks are covered with subhorizontally lying Cretaceous-Paleogene-Neogene masses in whose cross section permeable sand-and-gravel and impermeable aleurite-clayey benches alternate repeatedly.

Two types of uranium deposits have been discovered in the region.

The first (main) type of deposit is represented by stratiform roll deposits of uranium and uranium-selenium ore with rare metals. These ores are localized in permeable sandy benches of the cover on the redox barriers of the sheet oxidation zones. The sheet oxidation fronts are evident in several horizons (Lower and Upper Turonian, Campanian-Maastricht, Cognac-Santonian, and Paleogene) and extend for hundreds of kilometers to envelop the ledges of the Paleozoic basement. Uranium deposits are known in the Turonian (Uchkuduk), Cognac-Santonian (Bukinay), Campanian-Maastricht (Sugraly), Paleogene (Beshkak, Lyavlyakan), and other horizons. In several deposits, sheet oxidation fronts of several horizons that are drawn close together in a plane have turned out to be mineralized (Figure 7).

Ores of deposits of this type vary widely with respect to their uranium content (from hundredths to tenths of a percent). Depending on mining conditions and their quality, the ores are processed by the mining method (Uchkuduk, Sugraly) or by underground leaching (Bukinay, Beshkak, etc.). Rhenium, molybdenum, and scandium are extracted from these ores in addition to uranium.

The deposits of the second type are associated with the fold systems of the basement and are represented by stratiform (Rudnoye) or complex stockwork (Koscheka, Dzhantuar) deposits of uranium and uranium-vanadium ores in black shales of the Silurian-Ordovician age. The deposits are classified as Paleogenic and have been significantly transformed by surface processes of the Alpine cycle that have largely dictated their current appearance. The deposits' ores contain uranium in the amount of 0.1% to 0.2%. In some deposits vanadium is present in a significant concentration (1% to 3%).

The sheet oxidation deposits are the largest (the Uchkuduk deposit contains over 50,000 metric tons, and the Sugraly contains about 40,000 metric tons). The total uranium resources in the region associated with this type of deposit are estimated at over 400,000 metric tons. About 250,000 metric tons of proved and additional reserves of that amount are classified in the under-\$80/kg category.

The reserves of the deposits in black shales are relatively small and are classified in the higher production cost category (\$80-\$130/kg). The additional and proved resources of this type amount to about 18,000 metric tons.

The *Kirovograd uranium ore region* occupies the interfluvial area of the Southern Bug and Ingul. The city of Kirovograd is located at the region's eastern boundary. The region has a well-developed economic infrastructure.

From a geological standpoint, the region is confined to the central portion of the crystalline shield and corresponds to the Archean craton activated in the early Proterozoic. The region's structure is dictated by a large granite-gneiss dome whose core contains a granite mass consisting of two systems of granitoids of different ages and natures. The southern part of the mass is formed from anatectonic and intrusive potassium granites (about 2 billion years old), and the northern part is made up of granites-rapakivi and labradorites (1.7 to 1.8 billion years old). The peripheral zone of the dome is made up of gneiss and migmatites with small granite bodies (2.6 billion years old) (see Figure 3).

The granite-gneiss dome is cut by a series of deep faults in the submeridional and sublatitudinal directions that were deposited in the Archean and renewed in the early Proterozoic.

The formation of numerous bodies of metasomatic albitites is associated with the epoch of early Proterozoic activation. The position of these bodies is controlled by zones of fault breaks, and they are developed both along the gneiss of the dome's periphery and along the granites of its southern segment; however, they are absent in the granites-rapakivi. Uranium mineralization is noted only in a small portion of the albitite bodies and forms large stockwork-metasomatic deposits of complex shape. The main uranium deposits (Michurinskoye, Severinskoye, Vatutinskoye) gravitate toward two submeridional fault zones from the east and west of the core portion of the dome (see Figure 3).

The deposits' ores have a uraninite-brannerite composition. The ores' technological properties vary depending on their ratio of oxide and titanate forms of uranium and carbonate impurity. These technological properties in turn dictate whether the reserves are classified in the under-\$80/kg or \$80-\$130/g production cost category.

In addition to albitite-type deposits, the region has a number of small deposits associated with the process of potassium metasomatism and are close to early granitization in age (the Yuzhnoye, Kalinovskoye, Lozovatskoye, etc., deposits).

The region's largest deposit is the Severinskoye (about 50,000 metric tons). The total proved reserves in the region are estimated at 82,300 metric tons, and the additional and forecast reserves amount to about 250,000 metric tons. About 40% of the proved and additional reserves may be recovered for under \$80/kg, while the rest may be recovered for between \$80 and \$130/kg.

The *Strelitsa* uranium ore region is located in Eastern Transbaikalia and is located on the left bank of the central current of the Argun River. The region is one of Russia's oldest industrial regions and is well developed from an economic standpoint.

The Priargunsk Mining and Chemical Combine, which processes the uranium ores of the region's deposits, is located in the city of Krasnokamensk.

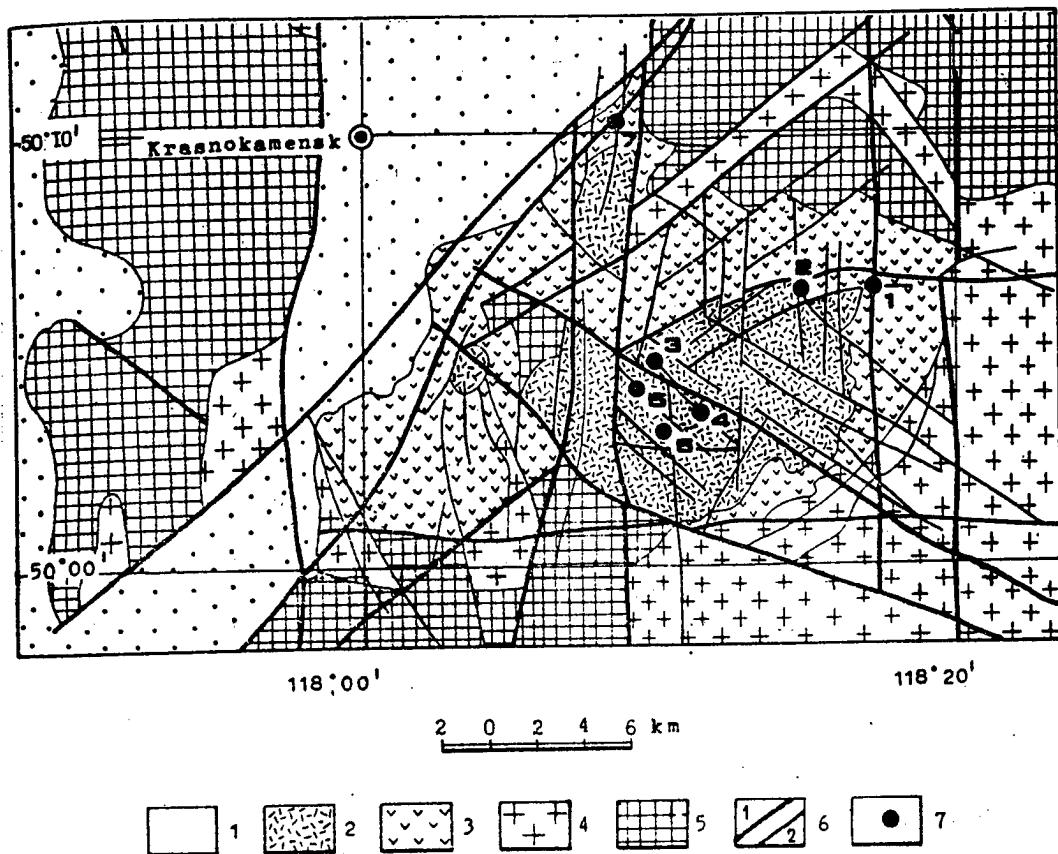


Figure 8. Geological map of the Strelitsa uranium ore region: 1, platform system (Carboniferous); 2-3, orogenic system (Jurassic); 2, upper subsystem (felsites, ignimbrites and tuffs of liparites, and sandstones); 3, lower subsystem (sandstones, ignimbrites and tuffs of dacites, andesites, basalts, and conglomerates); 4-5, preorogenic systems; 4, granites (Paleozoic); 5, metamorphites (Proterozoic); 6, faults; 7, uranium deposits: (1, Shirondukuyevskoye; 2, Streltsovskoye; 3, Tulukuyevskoye; 4, Yubileynoye; 5, Vesennye; 6, Novogodnaya; and 7, Dalnaya).

The Strelitsa region is unique from the standpoint of its concentration of uranium mineralization in a very limited area. Its geological position corresponds to an isolated tectonic block of a segment of Paleozoic Ural-Mongolian fold belt activated in Mesozoic rock.

Activation-stage structures represented by Upper Jurassic volcanic and Late Cretaceous graben-like depressions are located in the basement.

The volcanic depressions have an isometric shape and are made up of products of volcanic eruptions of the contrasting liparite-basalt series. Elevated concentrations of disperse uranium are characteristic of the late volcanic glass, which has an acidic composition.

The graben-like depressions have a linear shape and are made primarily of sedimentary coal-bearing deposits.

The Strelitsa region corresponds to the analogous caldera-type Upper Jurassic volcanotectonic structure, which measures about 20 km across. Its main distinction is the completeness of the profile of its volcanogenic-sedimentary system, which includes andesites, dacites, basalts, and liparites, as well as an abundance of interlayers of sediments and tuffs. This, combined with numerous steep tectonic faults, has dictated the creation of a local complex and thick system of subvertical and subhorizontal permeable channels connected to subhorizontal screens. Another distinction of this structure is the repeated appearance of processes of uranium concentration telescoped in time and space -- from stages of early granitization in the basement through a stage of concentration in volcanic products and to a stage of ore formation.

The uranium deposits of the Strelitsa region are classified as a type of hydrothermal vein-stockwork deposit. The deposits are located inside calderas. Their position is controlled by the juncture of a system of submeridional, northwest, and northeast faults. Its mineralization is localized at different stratigraphic levels of the profile of a volcanogenic-sedimentary system and in granites of the basement, forming steeply and gently sloping veins, complex linear and isometric stockworks, and even stratiform deposits developed throughout sheets of porous sandstones and tuffs (Figure 8).

From a composition standpoint, the ores are pure uranium (pitchblende) and uranium-molybdenum ores. Most have a uranium content of about 0.2%, the large stockworks contain up to 0.6% uranium, and the veins contain up to 1% uranium.

The largest deposits are the Streletsovskoye (vein bodies with reserves of more than 60,000 metric tons predominate) and the Tulukuyevskoye (a large stockwork with reserves of more than 35,000 metric tons). The smaller deposits (Yubileynoye, Novogodneye, and Dalneye) are primarily stratiform deposits (4,000 to 10,000 metric tons each). The total proved reserves throughout the region amount to 119,000 metric tons, the additional reserves amount to 70,000 metric tons, and the forecast reserves amount to 50,000 metric tons. All these reserves belong to the under-\$80/kg cost category. In addition, there are about 30,000 metric tons of proved, additional, and forecast reserves in the \$80-\$130/kg category.

The *Transural uranium ore reserve* occupies the interfluvial area of the Pyshma and Uy Rivers, the left tributaries of the Tobol River, which flows into the Irtysh. The nearest large center is the city of Chelyabinsk, which is located 80 km to the west. There are no mining enterprises in the region.

From a geological standpoint, the region is the edge of the young Western Siberian platform with a Hercynian fold basement. The cover includes Jurassic, Cretaceous, and Paleogenetic-Neogenic sediments.

The uranium deposits are classified as deposits of the stratiform ground-infiltration type and correspond to two age epochs -- the Later Jurassic and the modern.

The deposits of the Later Jurassic epoch occupy the leading position. They are confined as Upper Jurassic sands, sandstones, and aleurites that form a

system of paleovalleys cut into the rock of the basement and that are transgressively covered by water-impermeable Cretaceous, Paleogenetic, and Neogenic masses.

The uranium deposits are established mainly in the upper part of the paleovalleys. Their washdown basin includes Paleozoic acidic effusives with an elevated uranium content. In the eastern, northern, and southern directions, the thickness of the mass of post-Jurassic rock increases, and the region's boundaries are dictated by the depth of the productive paleosurface that is economically accessible for assimilation (Figure 9).

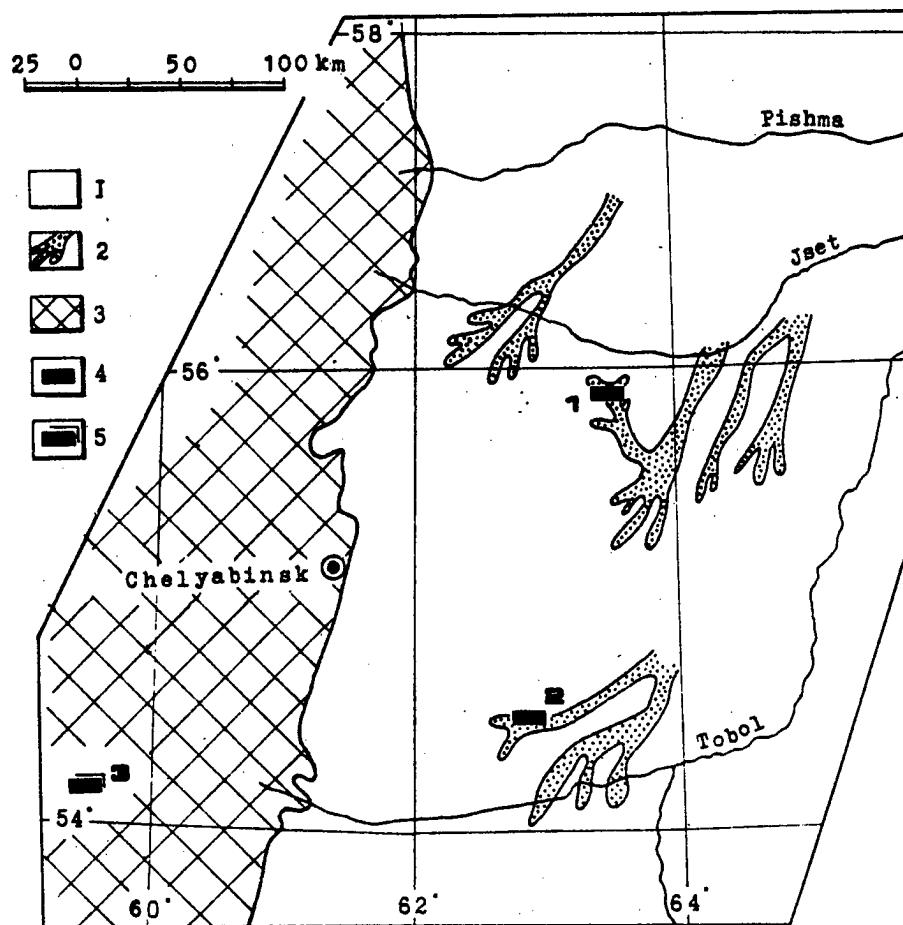


Figure 9. Geological map of the Transural uranium ore region: 1, platform system (Jurassic-Quaternary); 2, basal sediments of the platform system (Jurassic) forming paleovalleys on the buried surface of the fold system; 3, fold system (Paleozoic) on the modern surface; 4-5, uranium deposits of the exogenic series; 4, in the Jurassic sediments (1, Dolmatovskoye; 2, Dobrovolskoye); 5, in the modern sediments (3, Sanarskoye).

The ores of the deposits are poorer but suitable for processing by underground leaching. In addition to uranium, the deposits include rhenium, scandium, and rare earths that partially pass into the process solutions.

The deposits of the modern epoch are associated with carbonaceous- or peaty-sandy sediments of modern valleys. Their development is limited. The sole commercial deposit of this type (Sanarskoye) has now been mined out.

The total uranium resources are estimated as being on the order of 30,000 metric tons, with most being in the \$80-\$130/kg cost category. About 12,000 metric tons of them are classified as proved reserves (the Dolmatovskoye deposit).

The *Yenisey uranium ore region* corresponds to the basin of the upper current of the Yenisey river in the vicinity of the Western and Eastern Sayan ridges and separating their intermontane ravines. The city of Abakan is located in the center of the region. Economic assimilation of the region has been uneven. Its northern and central parts in the vicinity of the Yenisey valley are relatively developed. The southern portion and mountainous regions are in many areas uninhabited territories.

The region represents a Caledonian orogenic region that includes anticlinal uplifts and synclinal ravines. Precambrian granite-metamorphic systems have been discovered in the cores of the uplifts. The ravines are made up of subplatform, mainly red sandy-aleurite sediments of the Upper Devonian-Carboniferous period. Products of continental Devonian volcanic activity with both acidic and basic compositions are widely developed within their framework. Jurassic coal-bearing sediments belonging to the platform stage of development are present in the central parts of the ravines of the region's periphery.

Manifestations of vein uranium mineralization confined to fields of Devonian volcanic activity and anticlinal zones (Labyshkoye), as well as stratiform deposits associated with deposits of the Upper Devonian period, are known to exist in the region (Figure 10).

The latter type of deposits are the largest (Primorskoye, Ust-Uyuk). They are localized in horizons of gray sandstones among red masses of the very same composition and of Upper Devonian age. The ore bodies of the Primorskoye deposit are distinguished by the fact that they are not very thick (0.3 to 0.5 m) but are present in relatively high amounts (0.2% to 0.3%). The ores of the Ust-Uyukskoye deposit are mainly poor.

The total uranium resources in the region are estimated at somewhere on the order of 40,000 metric tons. This includes only 7,600 metric tons of the Primorskoye deposit in the proved category with products costs of between \$80 and \$130/kg. The reserves of the Ust-Uyukskoye and Labyshkoye deposits are classified as having a production cost above \$130/kg.

The region's forecast resources are tied primarily to the possibility of discovering new stratiform-type deposits. Searching for such deposits under the closed conditions of ravines is fraught with a great many problems, and the level to which the region has been studied remains extremely low. On the other hand, the complexity of the economic conditions existing for a significant portion of the region's territory have dictated the nonurgent nature of any such intensive studies at the present time.

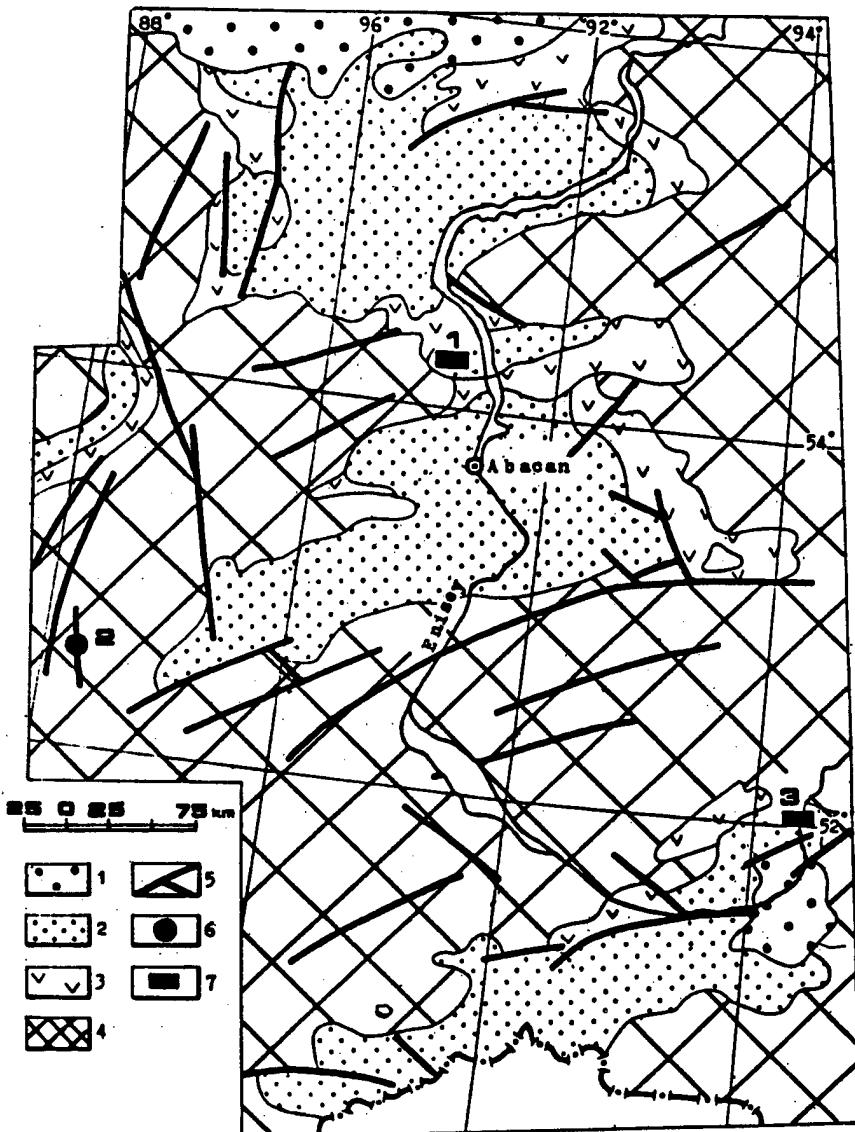


Figure 10. Geological map of the Yenisey uranium ore region: 1, platform system (Jurassic); 2-3, orogenic system (Devonian-Caledonian); 2, Late Neogene terrigenous (Devonian-Caledonian); 3, early orogenic volcanic (Devonian); 4, preorogenic systems (Proterozoic-Paleozoic); 5, faults; 6, uranium deposits of the endogenic series (2, Labyshkoye); 7, uranium deposits of the exogenic series (1, Primorskoye; 3, Ust-Uyuk).

The *Central Transbaikal uranium ore region* extends in a northeastern direction from the headwaters of the Ingoda river to the basin of the Nercha and Kuenga Rivers, which are the left tributaries of the Shilka River. The city of Chita is located in the center of the region.

The region is weakly assimilated from an economic standpoint. There are no uranium industry processing enterprises in the region.

From a geological standpoint, the region corresponds to the Mongolia-Okhotsk zone separating regions of Caledonian and Hercynian stabilization that have been significantly altered by subsequent Mesozoic tectonomagmatic activation.

Uranium deposits of several geological types are known to exist in the region. Manifestations of uranium mineralization of the vein-stockwork type in volcanic systems (the Strelitsa type) are linked with volcanotectonic structures of the Upper Jurassic-Lower Cretaceous deposits. The largest of them are the Olovskoye deposit, which is characterized by interstitial surfaces and horizons of porous rock of a layered mass of volcanic and sedimentary origin.

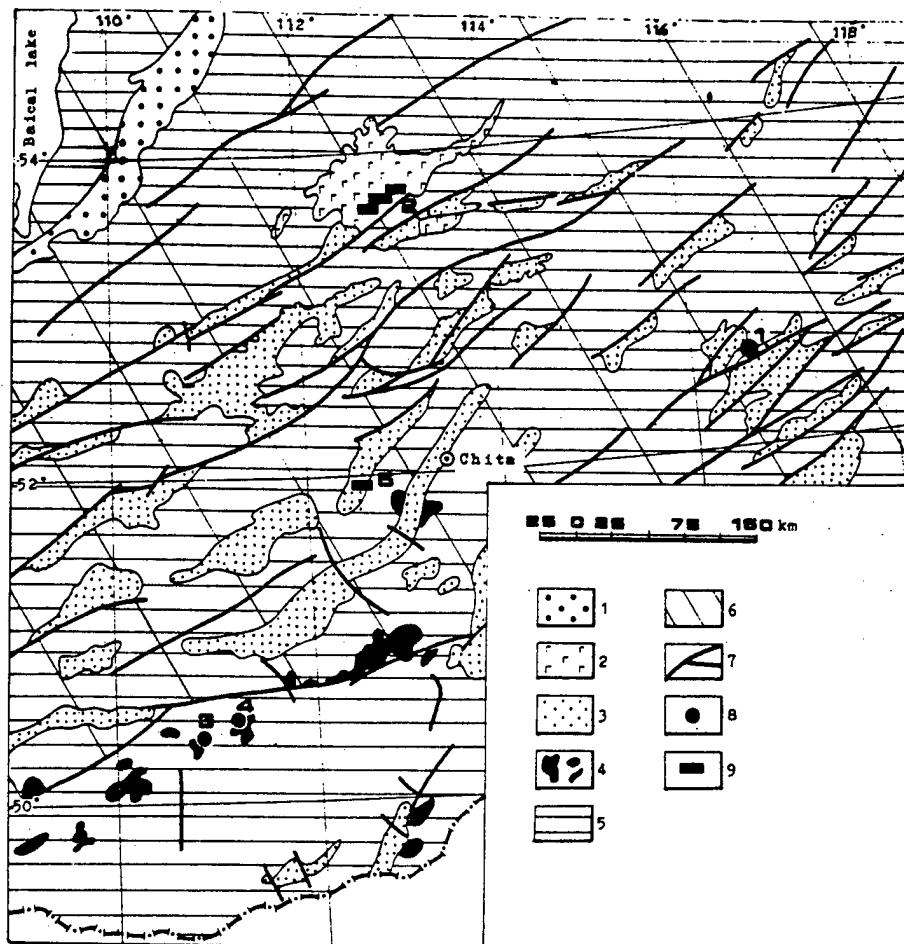


Figure 11. Geological map of the Central Transbaikal uranium ore region: 1-2, riftogenic system (Quaternary): 1, terrigenous sediments; 2, basalts; 3, platform system: coal-bearing terrigenous sediments (Carboniferous) deposited in sites on the vulcanites of the orogenic system (Jurassic): granites (Jurassic); 5-6, preorogenic systems: 5, of Hercynian stabilization; 6, of Caledonian stabilization; 7, faults; 8, uranium deposits of the endogenic series (1, Olovskoye; 3, Gornoye; 4, Berezovoye); 9, uranium deposits of the exogenic series (2, Vitim region; 5, Stepnoye).

Unique vein deposits in Mesozoic highly radioactive granites represent another type of deposit. Their ores consist exclusively of silicate hexavalent uranium (the Gornoye and Berezovye deposits).

Stratiform deposits in Lower Cretaceous coal-bearing graben-like ravines (the Stepnoye deposit) form a third type of deposit (Figure 11).

The ores of all of these deposits are mainly poor, although individual blocks the Gornoye deposit are made up of rich lump ores.

The region's total reserves are estimated at somewhere on the order of 40,000 metric tons; the reserves of the Olovskoye deposit account for 15,000 metric tons of that amount. All of the reserves are classified in the \$80-\$130/kg category.

The *Vitim uranium ore region* is located in the Northern Transbaikal region and occupies a portion of the plateau of the same name between the Vitim River and its left tributary, the Amalat River.

The region is not economically developed.

The region's geology is dictated by its position in the zone of the modern Baikal rift, and its area is dictated by a field of Quaternary basalts lying on a granite-metamorphic-Quaternary Proterozoic base. The thickness of the basalt cover is relatively small, ranging from 10-30 to 200 m. A portion of the Ancient Quaternary peneplain with its system of paleovalleys made of sands, aleurites, and chlidolites with a large amount of organic matter (see Figure 11) has been protected from erosion under this cover.

The ground-infiltration-type uranium deposits are confined to the paleovalleys' headwaters. Most of the deposits are located in inundated rock below the boundary of the multiyear permafrost, which makes it possible to recover them by underground leaching. Their uranium content amounts to hundredths of a percent.

Individual deposits corresponding to isolated paleovalleys have small reserves (ranging from hundreds to a few thousands of metric tons of uranium). The well-developed network of paleovalleys and the high frequency with which deposits are encountered in them has, however, made it possible to estimate that the region's total resources will amount to more than 60,000 metric tons. Because of the remoteness and unassimilated nature of the region, these resources are considered to correspond to the \$80-\$130/kg cost category. About 24,000 metric tons of these resources are classified as proved reserves.

The *Onega uranium ore region* occupies the northern shore of Lake Onega.

From a geological standpoint, the region corresponds to the Onega ravine, which is a large depression embedded in an Archean-Lower Proterozoic granite-gneiss basement and which is made up of sediments of a Karelian system of Proterozoic rock represented by conglomerates, shales (including black schungite shales) and dolomites, with numerous diabase sills and dikes. The formations of the ravine are intersected by a number of submeridional zones.

The sediments within the confines of these zones are crumpled into large linear folds and broken up by faults (Figure 12).

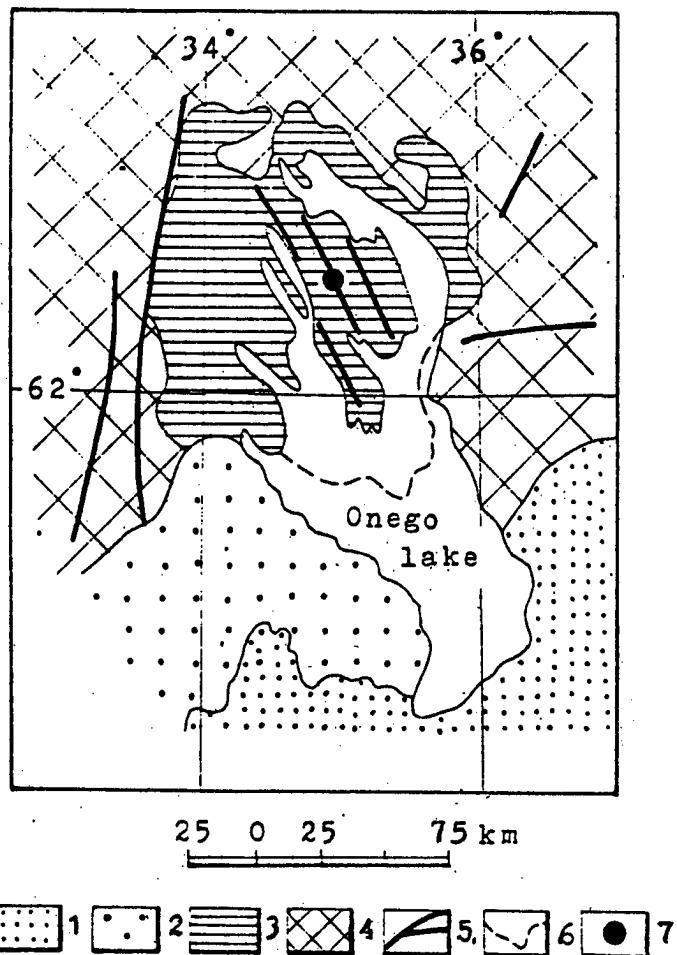


Figure 12. Geological map of the Onego uranium ore region: 1-2, platform system: 1, Paleozoic sediments; 2, Riphean sediments; 3, protoplatform system: schungite shales, dolomites, diabases (Proterozoic); 4, metamorphic system (Archean-Proterozoic); 5, faults; 6, boundary of the propagation of the protoplatform system under the lake's water area; 7, Padma uranium deposit.

The known uranium deposit (Padma) is localized in a zone of fold-break dislocations close to the fault and represent a stockwork of small vertical duration that is extended in a lateral direction. The mineralization is polygenic and polychronous in nature. The uranium mineralization (pitchblende, uraninite) is accompanied by elevated concentrations of vanadium (1% to 3%), bismuth, selenium, copper, molybdenum, gold, and platinoids. Their uranium content ranges from 0.1% to 0.25% and reaches values up to entire percentage points in isolated sections.

The proved uranium reserves at the Padma deposit are estimated as amounting to 2,000 metric tons, and the additional reserves are estimated at 3,000 metric tons.

The *Far Eastern uranium ore region* encompasses the Ussurisk and Amur Basins, the east of the Lensk Basin, the Okhotsk shore, and the Kolyma Chukotka Basins. No systematic explorations of this vast area for uranium have been conducted.

With the exception of the extreme southern regions and a part of the gold-bearing regions of Kolyma and Chukotka, this entire territory remains economically undeveloped.

From a geological standpoint, the region corresponds to the western segment of the enormous Pacific Ocean moving belt. A number of ancient rigid masses of different stabilization times are established within its confines. These rigid masses underwent tectonomagmatic activation in the Late Mesozoic and Cenozoic periods and may be considered promising from the standpoint of the discovery of endogenic uranium deposits. They include the Khanka (upper current of the Ussuri River); the Bureya (the left bank of the Amur); the Okhotsk, Kolyma, and Chukotka masses; and the Aldan shield.

The specified hopes regarding exogenic deposits are tied to the systems of platform cover of the Upper Cretaceous and Cenozoic epochs.

At the present time only one vein-stockwork uranium deposit, i.e., the Lastochka, is known throughout the entire territory. It contains ores classified in the \$80-\$130/kg cost category.

The deposit is located in the southern part of the Bureya mass and is confined to a small volcanotectonic depression of Lower Cretaceous age that has been deposited onto a granite Paleozoic basement.

The deposit's proved reserves amount to about 4,000 metric tons, and the uranium content in its ores ranges from 0.1% to 0.2%.

Finds of uranium mineralization of this type are known in other regions of the Far East, specifically, in the Okhotsk and Chukotka masses. Manifestations of other types of endogenic uranium mineralization linked both with formations of activation and ancient stages of development, including types linked to the surfaces of ancient unconformities on the Aldan shield, are known throughout the entire territory of the Far East. No detailed geological study of these finds has been conducted.

The significant amount of geologically promising segments and manifestations of various types of uranium mineralization has made it possible to estimate the forecast uranium resources in the Far East as being rather large (300,000 metric tons). Geographic and economic conditions have made it necessary to classify these resources in the over-\$130/kg cost category, however, and to consider their recovery in the near future a nonurgent matter.

The *total uranium reserves and resources in the USSR* are estimated at 2 million metric tons. Table 1 presents summary data regarding these reserves and resources by region and cost category.

Table 1. Uranium Reserves and Resources in the USSR (in thousands of metric tons)

Region	Cost Category									Regional Total	
	<\$80/kg			\$80-\$130/kg			>\$130/kg			Thousands of Metric Tons	%
	Proved	Additional	Forecast	Proved	Additional	Forecast	Proved	Additional	Forecast		
Karamazarskiy	20	-	-	-	-	-	-	-	-	20	1.0
Stavropol	3.3	2	-	-	-	-	-	-	-	5.3	0.20
Krivoy Rog	28.15	2.25	-	2.6	2.9	-	-	-	-	35.9	1.8
Caspian	-	-	-	64.4	-	-	-	-	-	64.4	3.3
Balkhash	17.9	50	50	4	-	-	-	-	-	121.9	6.01
Kokchetav	72.4	9.2	-	26.8	30.4	70	-	-	-	208.8	10.4
Strelitsa	119.16	84.84	50	4.8	2.2	20	-	-	-	281	14.0
Kirovograd	44.0	71.5	-	38.35	111.65	70	-	-	-	335.5	16.7
Kyzyl Kum	155.6	106	100	9.7	8.34	60	-	-	-	439.64	22.01
Transural	4.4	0.1	-	12	2.5	15	-	-	-	34	1.7
Yenisey	-	-	-	7.6	2.4	20	7.16	6	-	43.16	2.1
Vitim	-	-	-	23.7	3.8	40	-	-	-	67.5	3.4
Central	-	-	-	20.7	8.3	5	-	-	-	34	1.7
Transbaikal	-	-	-	-	-	-	-	-	-	-	-
Far Eastern	-	-	-	3.9	-	-	-	-	-	303.9	15.3
Onega	-	-	-	2	3	-	-	-	-	5	0.2
<b>Total</b>	<b>464.91</b>	<b>325.89</b>	<b>200</b>	<b>220.55</b>	<b>175.49</b>	<b>300</b>	<b>7.16</b>	<b>6</b>	<b>300</b>	<b>2,000</b>	<b>100.0</b>
<b>Including:</b>											
Proved	-	-	-	-	-	-	-	-	-	692.62	34.6
Additional	-	-	-	-	-	-	-	-	-	507.38	25.4
Proved + Additional	-	-	-	-	-	-	-	-	-	1,200	60.0
Forecast	-	-	-	-	-	-	-	-	-	800	40.0

As follows from Table 1, the total amount of reserves classified as proved amounts to 692,620 metric tons, i.e., 35% of the total estimate of reserves and resources. Of this amount, 464,910 metric tons are classified in the under-\$80/kg category, 220,550 metric tons are classified in the \$80-\$130/kg category; and 7,160 metric tons are classified in the over-\$130/kg category (67%, 32%, and 1%, respectively).

The additional reserves amount to 507,380 metric tons or 25% of the total estimate. Of that amount, 325,890 metric tons are in the under-\$80/kg category, 175,490 metric tons are in the \$80-\$130/kg category, and 6,000 metric tons are in the over-\$130/kg category (64%, 34%, and 2%, respectively).

The total proved and additional reserves amount to 1,200,000 metric tons or 60% of the total estimate of reserves and resources.

The forecast resources of known or assumed new regions are estimated at 800,000 metric tons. Of that amount, only 300,000 (38%) are tied to new, still-undiscovered regions.

### 3. Commercial-Genetic Types of Uranium Deposits

The accepted practice in the Soviet Union is to classify uranium deposits in three main series: endogenic, exogenic, and polygenic.

Each of the specified series includes deposits characterized by stable links with specified conditions of the geotectonic development of the earth's crust and similar ore deposition processes.

The endogenic series includes deposits formed under conditions of the circulation of thermal solutions generated during the course of tectonomagmatic processes of the stages of the development of the earth's crust of the ancient and young platforms.

The exogenic series includes deposits whose formation model conforms to subsurface conditions of the circulation of solutions of atmospheric origin in deposits of the cover of platforms as they developed in a stable manner or during the course of tectonic activation.

The polygenic series includes deposits whose formation was dictated by the successive (over the course of time) combination of ore-generating processes of the endogenic and exogenic types.

In the world practice commercial types of uranium deposits have received descriptive conditional names based on the following different leading features: enclosing rock, structural and morphological features, etc.

The authors of the present report have adhered to the Soviet classification scheme, providing the necessary explanations when domestic types of deposits are compared with types identified in the world practice. It should be noted that commercial uranium deposits of the ancient uranium-bearing conglomerate type are not known to exist within the territory of the USSR. Neither are any of the ancient unconformities that play a noticeable role in the world uranium resource balance known. In addition, large deposits of other types that are only sparsely represented or else totally unknown in other countries have also been discovered in the USSR.

The worldwide uranium resource balance (with consideration for data on the USSR) has turned out to be more leveled out with respect to different types. Furthermore, these data underscore the reigning position of uranium deposits in sandstones as a globally apparent highly productive type of uranium concentration. Presented below are the concise characteristics of the main types of deposits of the endogenic, exogenic, and polygenic series.

### Endogenic Series

This series includes the following types of uranium deposits: stockwork-metasomatic in albitites connected with processes of alkaline metasomatism in regions of protoactivation and vein-stockwork deposits in orogenic systems of Phanerozoic fold regions.

The total resources in the under-\$130/kg category in the USSR associated with deposits of the endogenic series are estimated at 717,000 tons, which amounts to more than 60% of all such resources (Table 2).

Table 2. Distribution of Uranium Reserves and Resources in the USSR

Deposit Type	Proved + Additional Reserves		Forecast Resources	
	Category \$130/kg			
	Metric Tons	%	Metric Tons	%
Vein-stockwork:				
in continental volcanic systems	273,600	23	70,000	14
in fold systems	152,800	13	75,000	15
Stockwork-metasomatic	290,900	25	70,000	14
in albitites				
Stratiform in sandstones:				
infiltration with sheet oxidation	315,100	26	210,000	42
same but ancient	10,000	1	20,000	4
infiltration with ground oxidation	57,000	5	55,000	11
Osseous detritus	64,000	5	-	-
Stratiform and stockwork in black shales	23,000	2	-	-
Total	1,186,800	100	500	100

*Stockwork-metasomatic deposits associated with the process of alkaline metasomatism in regions of protoactivation.* The deposits of the Krivoy Rog and Kirovograd regions are included among deposits of this type. Their formation is associated with the culminating stage of the formation of the Archean-Proterozoic crystalline basement of the Eastern European ancient platform. Ore formation (1.8 billion years) followed the stage of regional granitization (2.0 billion years) but occurred close to the time of the formation of the latest granite masses of rapakivi.

The ore formation process was both proceeded and directly accompanied by intensive alkaline metasomatism of the granite-metamorphic substrate. Large bodies of albitites formed. The position of these bodies is controlled by systems of faults. They include bodies deposited in the stage of plastic deformation of the medium (blastomylonite seams) and later bodies that were deposited closer in time to albitization and ore formation corresponding to brittle deformations. Zones of bulk cataclase of rock using albitizing and ore-bearing solutions were formed in conjunction with renewed ancient and young faults (Figure 13).

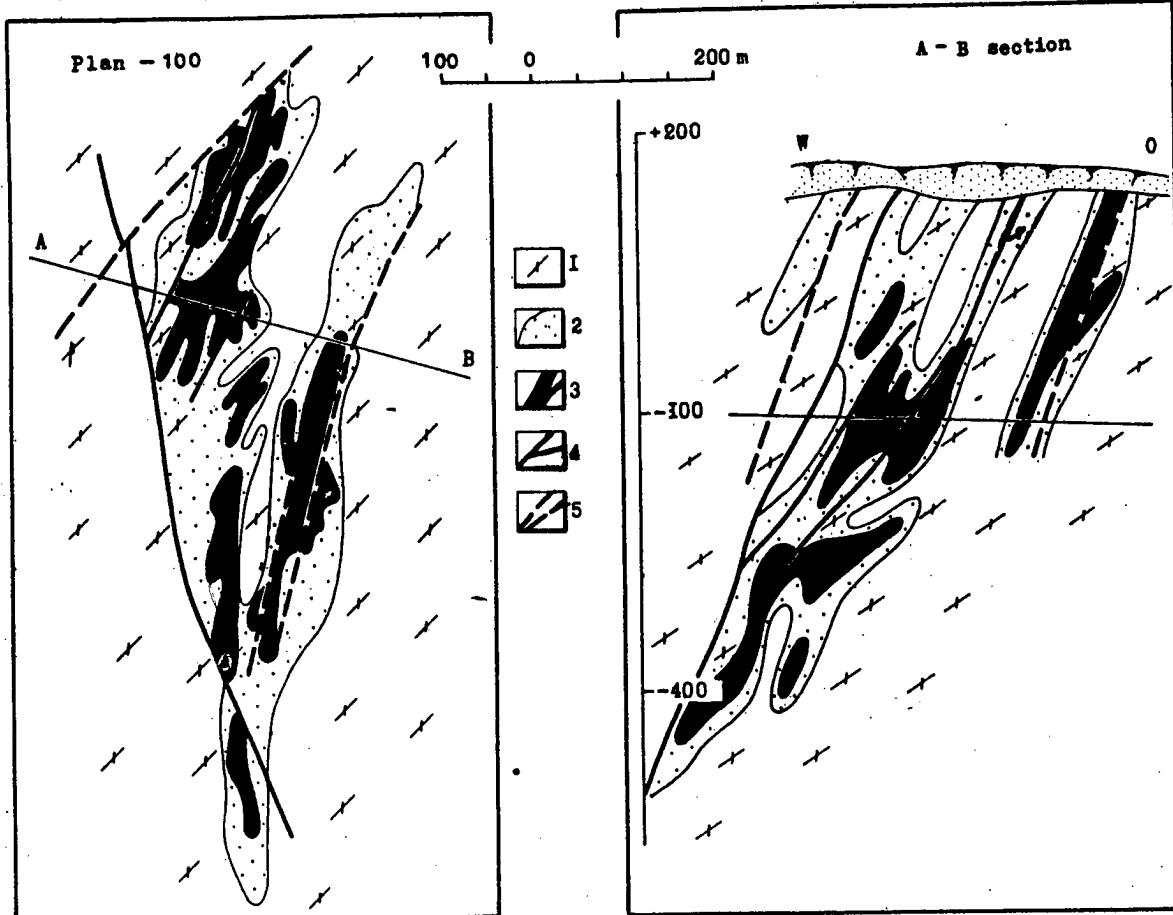


Figure 13. Plane of the horizon 100 m (left) and profile along the line A-B (right), Vatutinskoye uranium deposit: 1, gneiss, granites, migmatites (Archean); 2, zones of cataclase and albite metasomatism (albitites); 3, uranium ores; 4-5, faults; 4, blastomylonite seams; 5, zones of brecciation.

The albitization is developed along a different substrate: granites, gneiss, migmatites, and ferrous quartzites. Selective development of albitization throughout one or another variety of rock is often observed within the confines of specific deposits, however.

The uranium deposits of the Kokchetav mass are more ancient and correspond to the Later Caledonian epoch of orogenesis (with an average absolute age between 360 and 410 million years versus 260 to 280 million years in Europe). All these deposits are classified as being of the stockwork type. The vein-type

deposits known in the Ore Mountains (Pshibram, etc.) are not characteristic for them. Finally, unlike the European deposits, the deposits of the Kokchetav mass have not been found to have any close spatial connection with specified granite intrusives.

The deposits of the Kokchetav region are localized in different rock: shales, arkoses, jasperoids, limestones, granites, metavulcanites, etc., dating from the Silurian to Devonian periods.

The leading factor dictating the deposits' location is the nodes of intersection and junction of the long-lived faults.

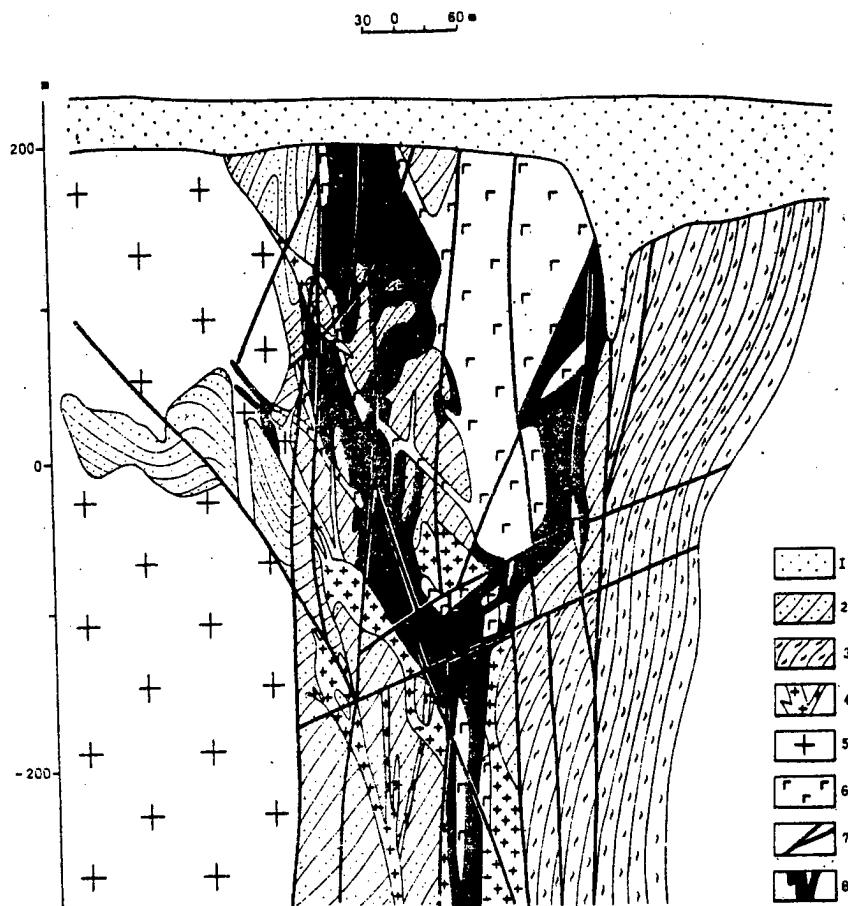


Figure 14. Geological profile of the Grachevskoye uranium deposit: 1, modern sediments and weathering crust; 2-3, vein deposits; 2, sandstones; 3, limestones and shales; 4, dikes of granite-porphyrines (Silurian-Devonian); 5, leucocratic granites (Silurian-Devonian); 6, gabbro (Ordovician); 7, faults; 8, uranium ores.

The ore deposits represent flattened linear, lens-shaped, or pipe-shaped stockworks developed along tectonic zones of crushing. The Grachevskoye deposit is located in unique breccia of an explosion pipe (Figure 14). Many deposits have been traced to significant depths (more than 1 km).

The alterations in the enclosing rock surrounding the ore are alkaline (albitization) in some places and acidic (sericitization-silisification) in others. The first type is especially characteristic for the ores of the Grachevskoye and Manygayskoye deposits, whereas the second type is characteristic for the Vostok and Balkashinskoye deposits.

Pitchblende, often in association with coffinite, is the main mineral at most of the deposits. Molybdenite is a characteristic associated mineral. At selected deposits (Zaozernoye), the uranium metallizing process is frequently represented by uranium-containing apatite.

The resources of this subtype of deposit account for about 13% (a total of 228,000 metric tons) of the balance of the country's total resources (in the under-\$130/kg category).

*Vein-stockwork deposits in continental volcanic systems* are very widespread within the territory of the USSR. They are known to exist in the central masses of the Tyan-Shan and Transbaikal segments of the Ural-Mongolian orogenic belt and in analogous structures of the Pacific Ocean orogenic belt.

Included among this type of deposit are the Karamzarskiy, Balkhash, and Strelitsa uranium ore regions, as well as the Lastochka deposit in the Bureya mass in the Far East. Despite the extensive development of such deposits in the USSR, deposits of this type are virtually unknown in other countries. The Marysville deposit in the United States and small deposits on the continent of South America (the Los Frailes region) and several others may be considered possible analogues.

In the USSR deposits of this subtype date from the Upper Devonian (the Balkhash region) and Permian-Carboniferous (Karamzar) to the Upper Jurassic (the Strelitsa region) and Late Cretaceous (Lastochka). The deposits of the secondary segment of the Pacific Ocean belt date from the Cenozoic.

The deposits under consideration are distinguished by their close temporal and spatial link to volcanotectonic structures of the cupola or caldera type located on a consolidated, more ancient and frequently granitized basement and controlled by zones of deep faults. Such structures are formed from alternating horizons of ignimbrites and lavas with various compositions separated by interlayers of tuffaceous and fragmental rock and cut by subvolcanic intrusive and extrusive bodies with an acidic composition.

The uranium metallizing process is located in rock of volcanic structures and sometimes also in the rock of their basement. It develops along steeply and gently sloping ruptures and contact zones of different stratified and pipe volcanic formations and horizons of pyroclasts and sedimentary rock, i.e., it uses the system of permeable channels and screens created by the heterogeneous structure of volcanic formations and the tectonic ruptures intersecting them (Figures 15 and 16).

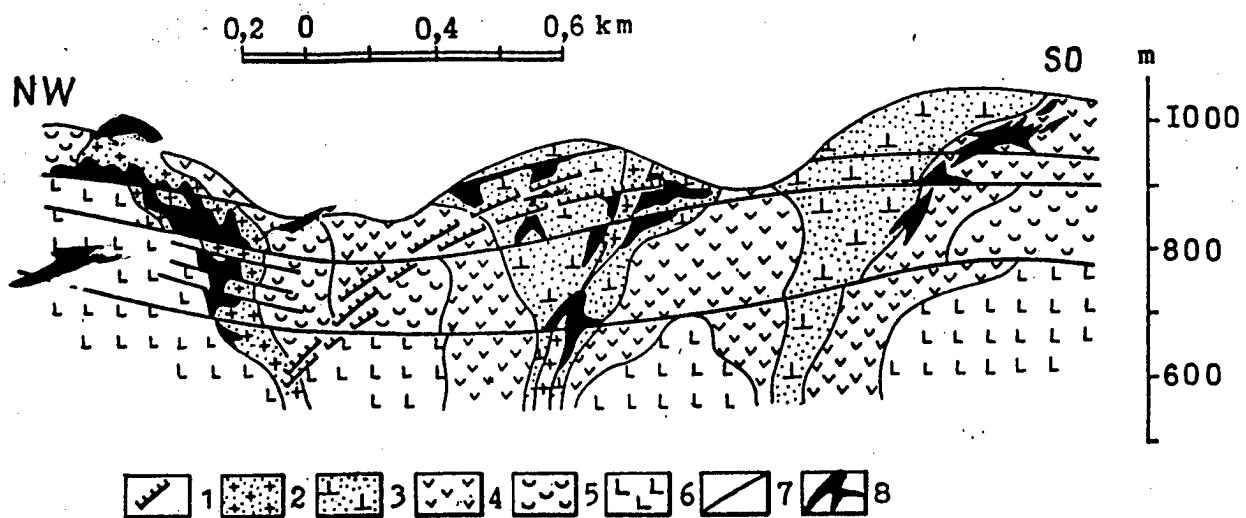


Figure 15. Geological profile of the Kattasay and Alatanga uranium deposits: 1, dikes with basic and acidic compositions (Permian); 2-5, rock of the late orogenic system (Permian); 2, granite-porphyrries, granoselenite-porphyrries; 3, quartz porphyries; 4, felsites, felsite-porphyrries; 5, ignimbrites and tuffs; 6, early orogenic system (Caledonian), andesite-dacites; 7, faults; 8, uranium ores.

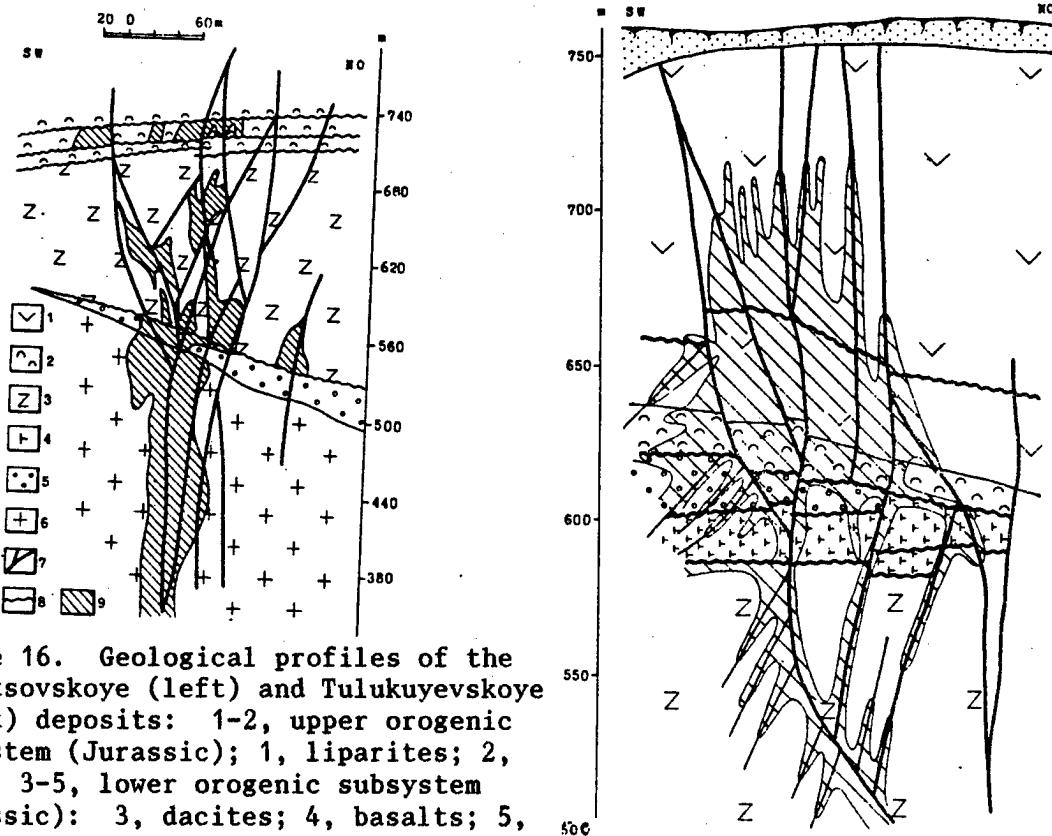


Figure 16. Geological profiles of the Streltsovskoye (left) and Tulukuyevskoye (right) deposits: 1-2, upper orogenic subsystem (Jurassic); 1, liparites; 2, tuffs; 3-5, lower orogenic subsystem (Jurassic): 3, dacites; 4, basalts; 5, conglomerates; 6, preorogenic granites (Paleozoic); 7-8, faults; 7, steeply sloping; 8, interlayer; 9, uranium ores.

The alterations of the enclosing rock at deposits of this type are generally expressed in sericitization and silicification or hydromicatization, which indicates the acidic nature of the mineral-forming solutions. In some deposits of the Balkhash region, however, albitization of the rock confirming the alkaline nature of the solutions is observed.

It has been established at the Strelitsa deposit that the hydromicatite type of alterations characteristic for the upper and middle parts of the deposit's profile are replaced by albitization in deeper horizons. The acid-base conditions of ore deposition in this type of deposit are thus rather variable.

The main uranium mineral is generally pitchblende. It is sometimes associated with coffinite. The ores have a mottled, veined, and sometimes massive texture. Molybdenum sulfides (molybdenite and jordisite) are noted in significant quantities in many of the deposits, and fluorite is noted at several deposits (Streltsovskoye).

The ore deposits are extremely diverse from a shape standpoint and form complex systems of connected veins, stockworks, and stratiform bodies (see Figure 16). The total length of the systems of heterotype deposits along the lateral and vertical often reaches several kilometers (Streltskovoye, Kattasay-Alatanga).

The ores are generally characterized by the high contrast of their contents and by the presence of enriched segments and blocks containing uranium to an entire percentage point (Figure 17).

The total uranium resources associated with this subtype of deposit are estimated at 340,000 metric tons, which amounts to about 20% of the total resources in the under-\$130/kg category.

In toto, the resources of vein-stockwork deposits of both of the subtypes identified amount to about 570,000 metric tons or 34% of all resources. Vein-stockwork deposits thus occupy one of the leading places in the structure of the raw materials base in the USSR.

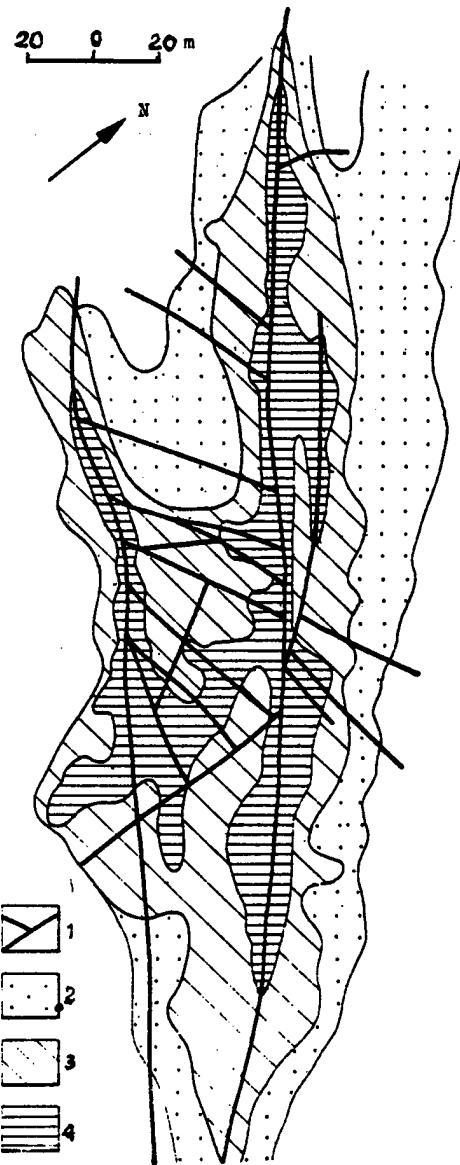


Figure 17. Plane of the horizon at 640 m (a fragment) of the Tulukuyevskoye uranium deposit: 1, faults; 2-4, uranium ores with the following uranium contents: 2, 0.03 to 0.1%; 3, 0.1 to 0.3%; 4, 0.3% to 1%.

## Exogenic Series

Stratiform deposits in sandstones occupy the leading position among deposits of the exogenic series in the USSR. Three subtypes of such deposits have been identified: infiltration deposits associated with fronts of sheet oxidation of artesian basins in the permeable rock of platform systems and infiltration deposits associated with ground-oxidation processes in the sediments of valleys of peneplainized surfaces of granite-metamorphic or fold systems. Each of these subtypes is known to include formations dating from submodern or more ancient periods. The second most important type of deposit in the exogenic series is that of unique deposits of uranium-bearing phosphatized osseous detritus of fish fossils in marine pyrite-bearing clays of platform systems.

The total uranium resources in the under-\$130/kg category associated with deposits of the exogenic series in the USSR is estimated at 446,000 metric tons, which amounts to about 38% of all such resources.

*Stratiform deposits in sandstones.* This collective term, which is widely used in world practice, applies to those deposits of the Kyzyl Kum, Yenisey, and Vitim regions that are associated with loose sediments of the platform cover or with sedimentary rock of orogenic recesses.

*Infiltration deposits in conjunction with fronts of sheet oxidation of the submodern stage* are represented by a large group of deposits in the Kyzyl Kum region and occupy first place in the exogenic group.

The formation of such deposits is associated with the activity of the acid-containing atmospheric waters that circulated in artesian basins formed in the stage of the activation of young platforms and that leached uranium out of crystalline rock in the feed areas and then deposited it on redox barriers on the path to the discharge regions.

This type of deposit is the most prevalent in the world. It has been studied and described in detail. The deposits of the Kyzyl Kum region are not especially different from the deposits known to exist in Wyoming and other similar regions. They are localized in sand seams, gravel deposits, or weakly cemented sandstones included among clays, aleurites, or dense sandstones. The age of the ore-enclosing benches ranges from the Lower Cretaceous to the Paleogene; however, the metallization process dates from the Lower Miocene.

Deposits with relatively rich ore (Uchkuduk, Sugraly) are known to exist in the Kyzyl Kum region. Their uranium content reaches tenths of a percent (Figure 18). The region also contains deposits with poor ores (Bukinay, Lyavlyakan, Beshkak, etc.) (Figure 19). The former have been partially mined out, whereas the latter have been worked exclusively by underground leaching.

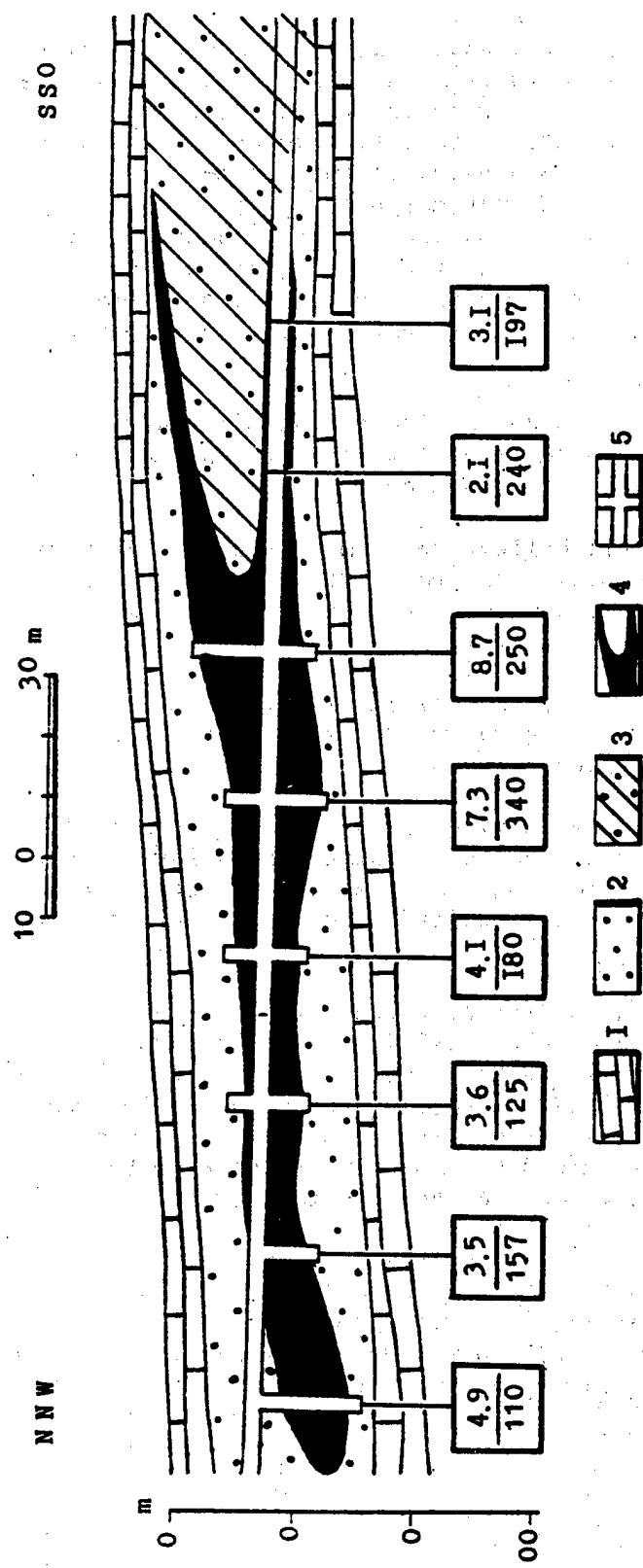


Figure 18. Geological profile (a fragment) of the Surgrala deposit: 1-2, Campanian-Maastricht deposits; 1, sandstones; 2, sands, 3, zone of sheet oxidation; 4, uranium ores; 5, mine developments. (The boxed numbers indicate metallization process parameters along the intersections: the number in each numerator designates thickness in meters, and the number in the denominator represents content as a percentage.)

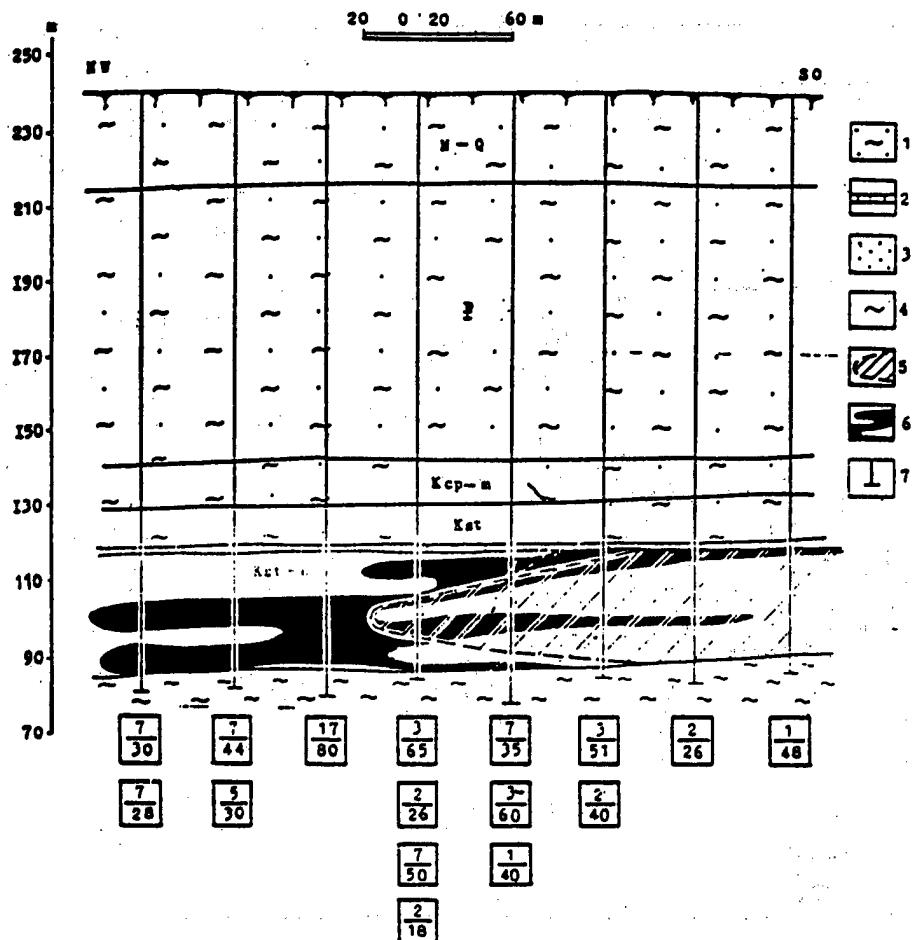


Figure 19. Geological profile of the Bukinay uranium deposit: 1, sediments of the overburden series (sands, sandstones, aleurites, clays); 2-4, sediments of the Cognac-Santonian ore-bearing horizon: 2, sandstones; 3, sands; 4, clays; 5, zone of sheet oxidation; 6, uranium ores; 7, boreholes. (The boxed numbers indicate metallization process parameters along the intersections: the number in each numerator designates thickness in meters, and the number in the denominator represents content as a percentage.)

The ore deposits in a cross section have the form of porous or complicated rolls, whereas those in a plane are in the form of elongated, weakly serpiginous strips with widths reaching hundreds of meters and with lengths reaching tens of kilometers (Figure 20).

The ores of most of these deposits are uranium; however, several deposits have been noted to have elevated contents of selenium, rhenium, vanadium, etc.

The total resources included in deposits of this type are extremely significant. They are estimated at 525,000 metric tons, which is about 31% of all resources in the under-\$130/kg category. Deposits of this type represent the leading type of deposit in the forecast resources group (210,000 metric tons or 42%).

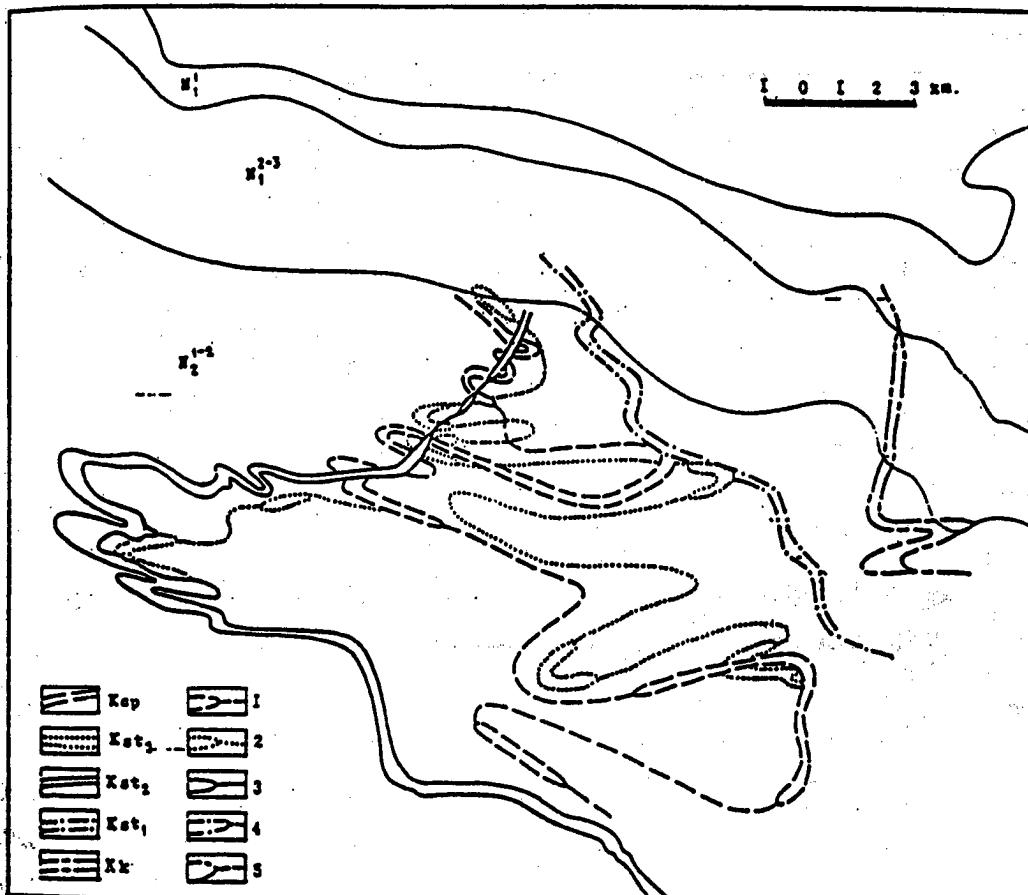


Figure 20. Geological map of the Kaginekh deposit: 1-5, fronts of sheet oxidation in different horizons of Cretaceous sediments (left) and their associated uranium ore deposits (right).

*Infiltration deposits in sandstones of the ancient stage are represented by the Primorskoye and Ust-Uyukskoye deposits in the Yenisey region, which date from the Upper Devonian. Elements of deposits shaped like rolls in their cross section and signs of their localization at the boundary between red and gray rock have been established at the Ust-Uyukskoye deposit. The Primorskoye deposits are localized entirely in gray horizons and do not possess the characteristic striplike shape in a plane or roll-like shape in their cross section that represents isometric sheet lenses. No consensus has been reached regarding the genesis of these formations.*

The total prospects of this type of deposit seem insignificant.

*Infiltration deposits associated with ground-oxidation processes in the sediments of valleys of peneplainized surfaces are rather common within the territory of the USSR. In the world literature similar formations are sometimes termed "basal" or "surface" deposits. Formations of the infiltration and evaporation types (uranium-bearing calcretes) have been identified among them.*

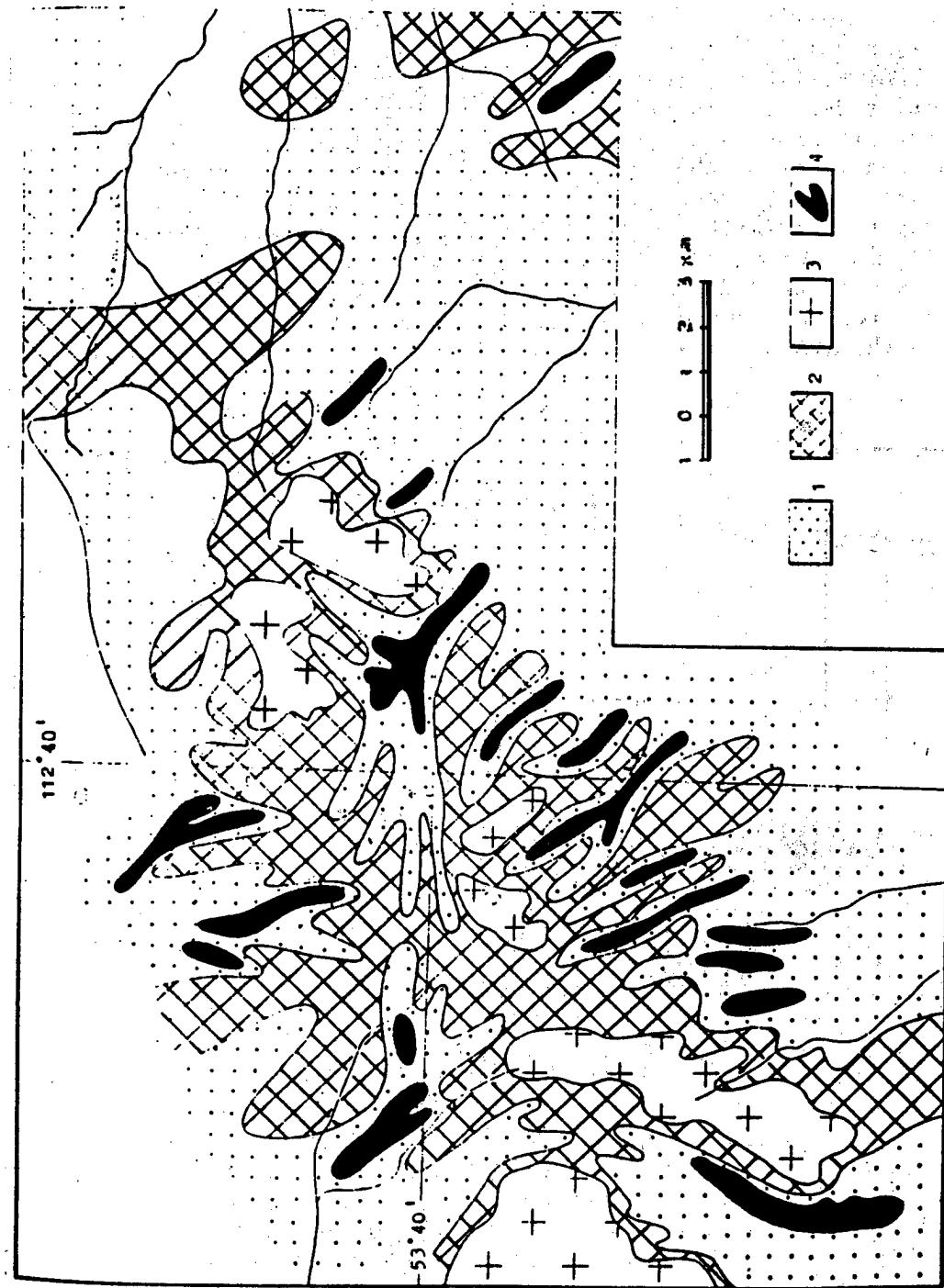


Figure 21. Geological map of the Vitim uranium ore deposit with its cover of Quaternary basalts removed: 1, sands, chlidolites (Oligocene-Miocene); 2-3, granite-metamorphic rock of the peneplain basement (Proterozoic): 2, buried under basalts; 3, extending out to the earth's modern surface; 4, uranium ores.

Infiltration deposits of Upper Jurassic, Miocene, and anthropogenic age are known in the USSR.

The formation mechanism of these deposits is similar. In the first stage, sediments that are significantly enriched in carbonaceous matter (up to entire percentage points) accumulate in valleys of the peneplainized surface under conditions of a humid climate. In the next stage, when the climate is replaced by a semiarid-semihumid climate, oxygen waters enter the sediments of the valleys from their sides where they leach uranium from the crystalline substrate and discharge it on the contrast barrier resulting from the organic chemistry processes. In the case of the ancient deposits, this was followed by burial of the peneplain with its system of valleys along with the ore deposits contained in them under transgressively lying younger masses. The latter process was evidently decisive for the formation of relatively high concentrations of uranium because the preservation of peneplain conditions inevitably led to the gradual destruction of a metallization process formed by erosion.

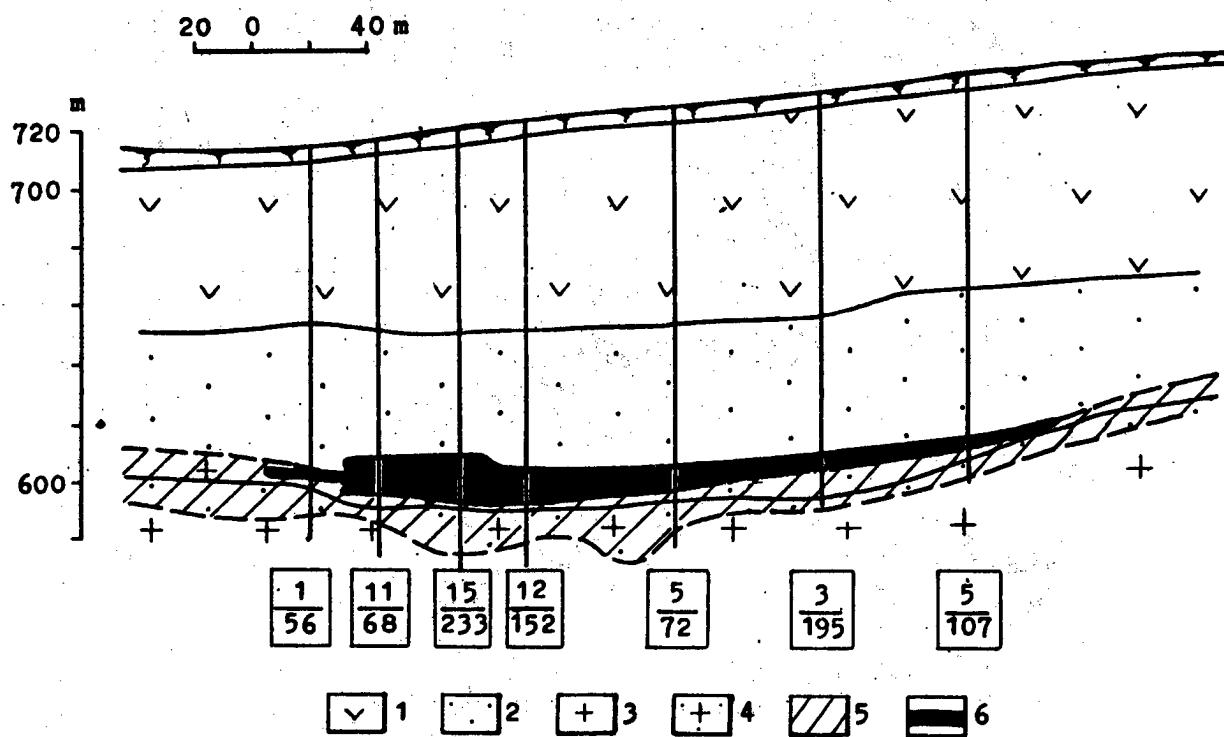


Figure 22. Geological profile of the Khiagdinskoye deposit in the Vitim region: 1, basalts (Quaternary); 2, sands, chlidolites (Oligocene-Miocene); 3-4, granite-metamorphic basement (Proterozoic); 3, erosion crust; 4, fresh rock; 5, oxidation zone developed from the sides of the paleovalleys; 6, uranium ores; 7, boreholes. (The boxed numbers indicate metallization process parameters along the intersections: the number in each numerator designates thickness in meters, and the number in the denominator represents content as a percentage.)

Two relatively large regions characterized by preservation of the Upper Jurassic and Oligocene-Miocene peneplains with a system of ore-bearing paleovalleys, i.e., the Transural and Vitim (see Figures 9 and 11) have been discovered in the USSR.

In the Transural region the Upper Jurassic peneplain covers Cretaceous-Paleogene-Neogene sediments with a total thickness of 300 to 700 m. In the Vitim region, the Oligocene-Miocene peneplain is buried under a cover of Quaternary basalts 10 to 200 m thick.

In a plane, the uranium ore deposits repeat the shape of the enclosing valleys and are up to several kilometers long and 50 to 300 m in thickness. The thickness of the deposits does not generally exceed 10 m. Their uranium content is low. Their mineral forms are represented by black pitchblende and minguetite (Figures 21 and 22).

Anthropogenic deposits of a similar type are known in the Kirovograd-Krivoy Rog and Transural regions; however, they are encountered (protected from erosion) sporadically and do not form accumulations with significant reserves.

The uranium resources associated with this type of deposit are estimated as being in excess of 100,000 metric tons and amount to about 7% of the total amount.

*Deposits of uranium-bearing phosphatized osseous detritus of fish fossils.* These deposits form the Caspian uranium ore region. They are confined to the specified stratigraphic benches in the cross section of the Paleogene deposits (Figure 23). The overburden bench is made of carbonate clays, and the bench above the ore is made of aleuritic clays. The ore-bearing bench is 0 to 200 m thick and made of gray and black clays with finely dispersed pyrite (melnikovite). The accumulations of uranium-bearing osseous detritus are confined to recesses in the surface of the underlying bench formed by the activity of underwater currents. The detritus-enriched layers of clay range in thickness from fractions of a meter to 1-2 m and stand out by virtue of their darker color. The detritus-bearing layers split in the direction along the incline of the recesses, as well as to their sides.

In a plane, the detritus-enriched zone corresponding to ore deposits has the form of tongues wedged deep into the paleobasin (see Figure 23). The osseous detritus is mainly shallow (1 to 3 mm) and crushed with traces of pelletization. The amount of bones ranges from 10-20 to 70%. The bone content is higher in the upper sections of deposits along the recesses' incline, and the fragments are larger. The bones consist entirely of uranium-containing carbonate-fluorine-apatite. The smaller bones are richer in uranium.

The genesis of the deposits is not yet entirely clear. It is likely that the accumulation of uranium in the bones occurred before they were buried at their modern depth, and the formation of the accumulations is likely associated with the activity of underwater currents. The possibility of that the uranium in the fish bones was partially accumulated while the fish were still alive, which could be one reason for their mass demise, cannot be excluded either.

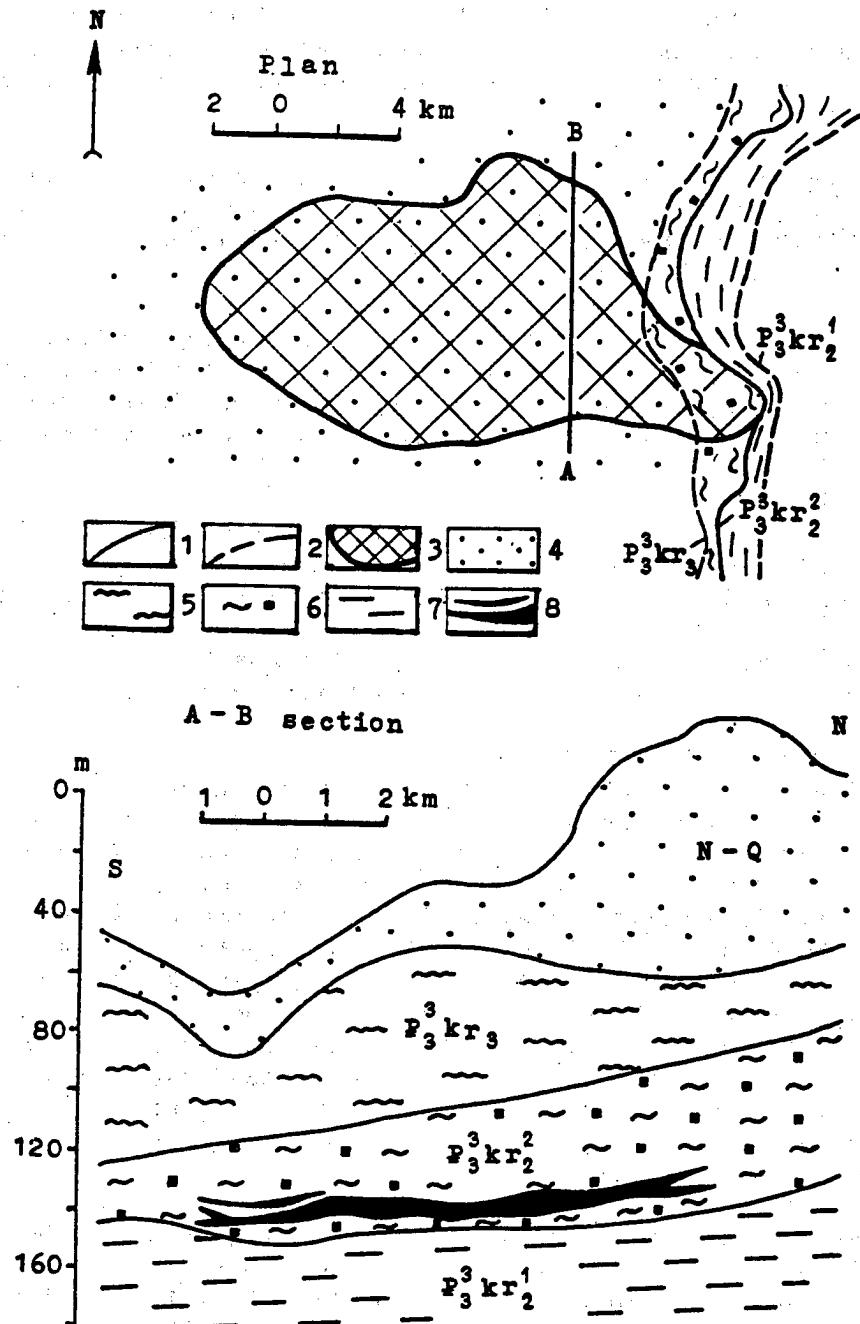


Figure 23. Plane of the Melovoye uranium deposit with the contour of the projection of the ore deposit on the surface (top) and profile along the line A-B (bottom): 1-4, designations for the plane: 1, outcropping of the ore-bearing layer to the surface; 2, outcroppings of the bench boundaries to the surface; 3, contour of the projection of the ore deposit to the surface; 4, overburden system (Neogene-Quaternary); 5-8, designations for the cross section: 5, aleurital clays; 6, pyrite-bearing clays; 7, carbonate clays; 8, layers of uranium-bearing osseous detritus.

The overall prospects of deposits of this type are limited. The known reserves amount to 64,000 metric tons, which is only about 4% of the total structure of the raw material base.

### Polygenic Series

This is the series in which Soviet geologists classify deposits of complex and not yet fully deciphered genesis that gravitate spatially toward regions of the development of carbon-containing shale formations of various age that are syngenetically enriched in uranium and characterized by a distinctly expressed polychronicity of ore formation. Two subtypes of such deposits have been identified. One is associated with the Lower Paleozoic black shale formations of the preorogenic system of the Kyzyl Kum region, whereas the other is associated with the Lower Proterozoic protoplatform schungite shales of the Baltic Shield (the Onega uranium-bearing region).

*The deposits in the Lower Paleozoic black shales of the Kyzyl Kum deposits form a compact group in the Auminzatau Mountain mass (see Figure 7). Coal-containing, phyllite-like, and siliceous shales have been identified in the cross section of the Lower Paleozoic shale formation. The coal-containing shales enclosing the metallization process are distinguished by their elevated concentration of uranium, vanadium, molybdenum, zinc, and other elements. The shales are cut by Late Paleozoic granites and are unevenly crumpled into folds.*

The deposits are located in the exocontact zone of a mass of carboniferous granites and controlled by faults along which intensive movement has occurred more than once all the way up to the Quaternary period.

The ore deposits have the form of complex stockworks or stratiform deposits. Up to a depth on the order of 300 m below the modern surface, they consist exclusively of phosphates and vanadates of hexavalent uranium (Figure 24). Pitchblende-coffinite deposits with ore sulfides are developed below. It has been established that the generations of pitchblende are associated with quartz-chlorite-sericite metasomatism, whereas the later formations are associated with argillite alteration of the rock. In isolated deposits (Rudnoye) vanadium is contained in the ores in a commercially significant amount. The concentrations of vanadium in the remaining deposits are low.

It is assumed that the process of the deposits' formation began with the hydrothermal stage of the Variscan cycle, continued with a hydrothermal stage into the epoch of Alpian tectogenesis, and culminated in a supergene stage. A redistribution of the early concentrations, including the original syngenetic uranium concentrations, likely occurred throughout all the stages.

The deposits in the Lower Proterozoic schungite shales of the Onega region are localized in zones of fold-and-fault dislocations and gravitate to the zone of tectonic contact of the schungite shales and dolomites. The ore deposits have a length of more than 1 km along the lateral, but are very short along their drop (10 to 50 m) with a thickness of 5 to 30 m. The position of the deposits is evidently partly controlled by an ancient (Riphean) oxidation zone developed from the surface. In addition, the composition of the ores,

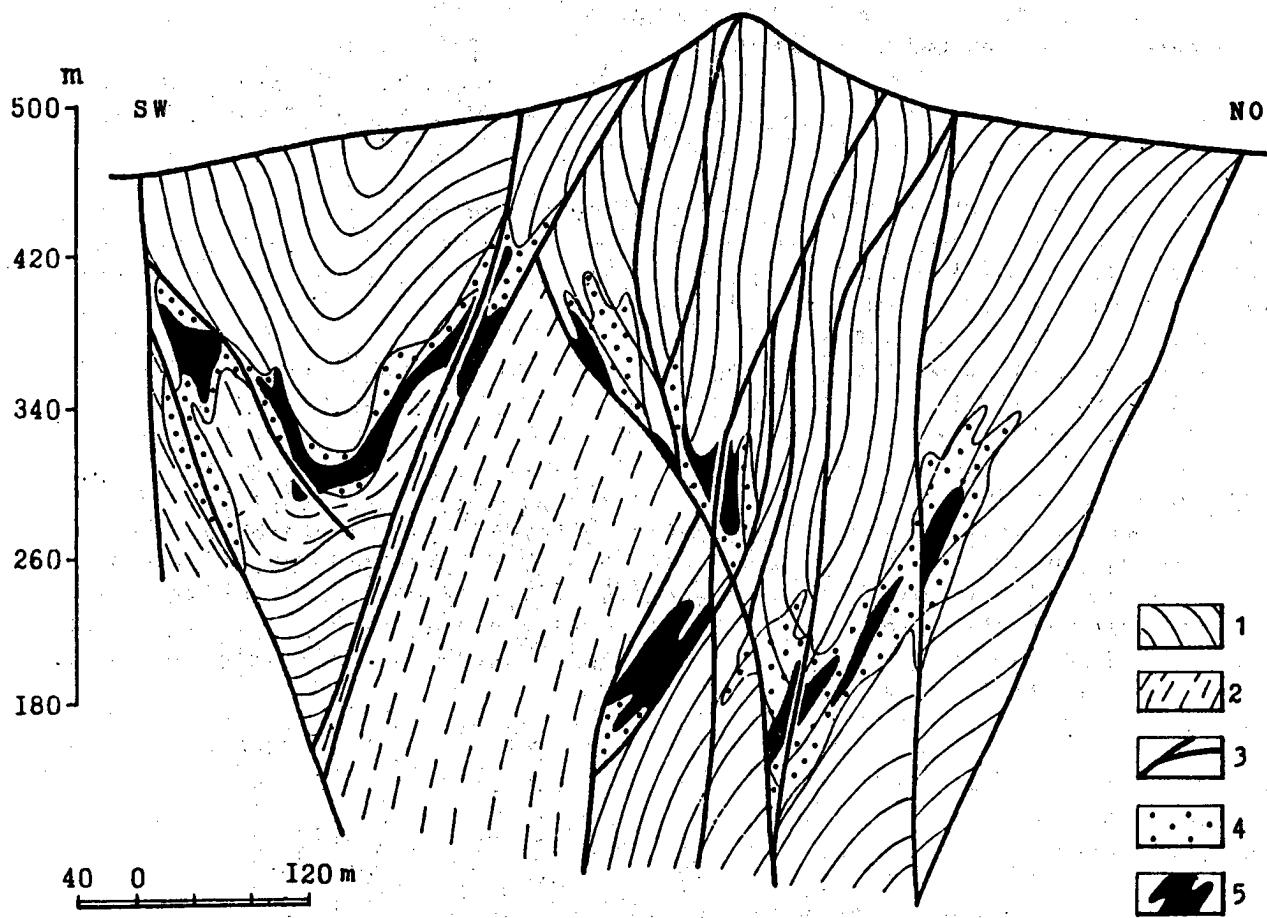


Figure 24. Geological profile of the Dzhantuar uranium deposit: 1-2, shales; 1, uranium-containing; 2, phyllite-like and siliceous; 3, faults; 4-5, uranium ores with the following uranium contents: 4, up to 0.03%; 5, more than 0.03%.

represented by pitchblende in association with bismuth selenides and gold and platinum impurities, and the development of the albite metasomatism around the ore indicate that endogenic processes were involved in their formation. The uranium mineralization appears against the background of earlier vanadium concentrations (roscoelite, oxides). Determinations of the absolute age of the ores have yielded values ranging from 0.6 to 1.8 billion years. The deposits have remained not very well studied (Figure 25).

The total resources of the polygenic deposits of the USSR are small (about 20,000 metric tons). Further geological research may change this, however.

Soviet scholars also classify what are termed "unconformity-type" deposits, i.e., the unique uranium deposits in Paleozoic black shales of Turingia (Germany) in the polygenic group. Deposits of this type are known to contain very significant quantities of uranium.

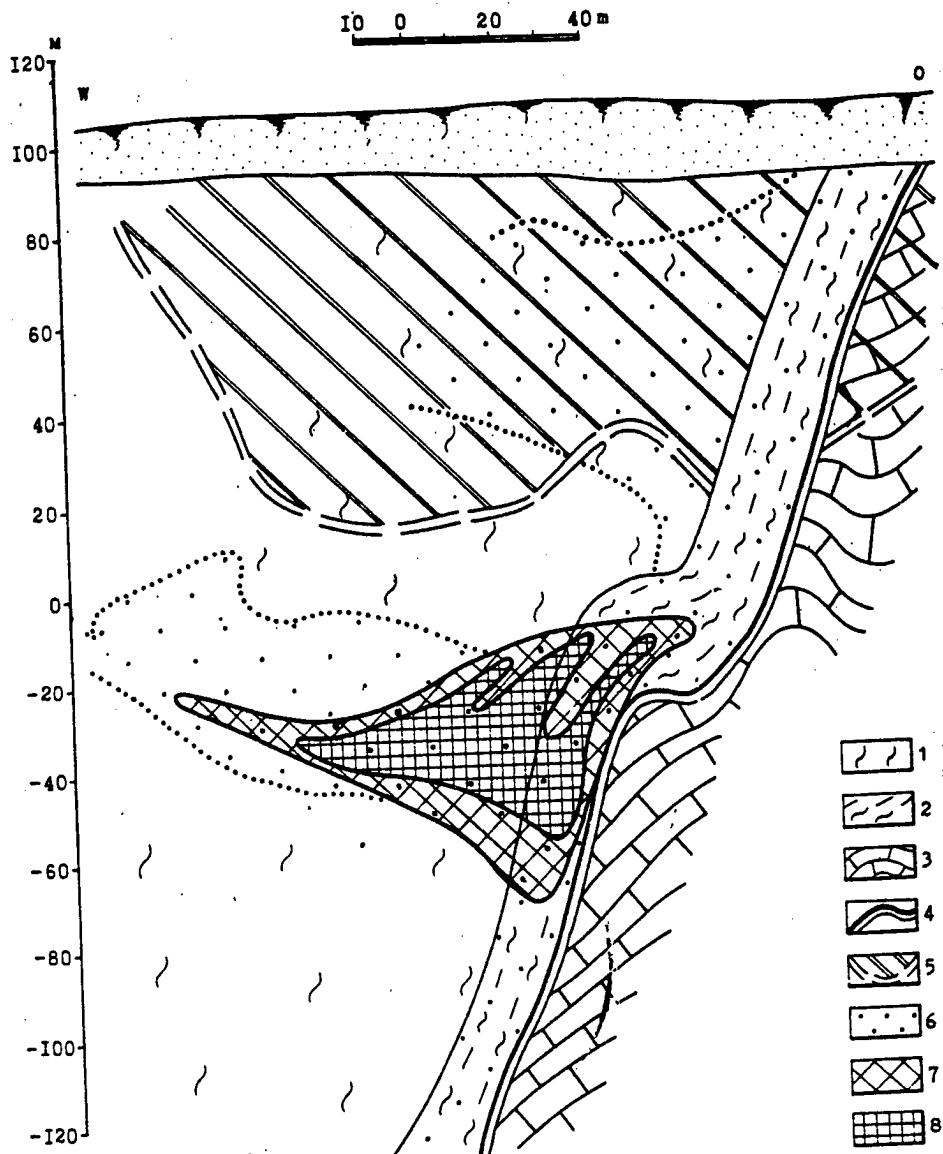


Figure 25. Geological profile of the Padma uranium deposit: 1-3, rock of the protogeosynclinal system (Proterozoic): 1, schungite shales; 2, the same but in a cataclase zone; 3, dolomites; 4, fault; 5, hematization zone; 6, albitization; 7, vanadium ores; 8, uranium-vanadium ores.

#### 4. Selected Spatiotemporal Laws of the Distribution of Uranium Deposits and Resources Within the Territory of the USSR

Analysis of the materials on the geology of uranium deposits of different commercial-genetic types indicates that uranium ore formation within the territory of the USSR appeared at specified periods in the development of the continental earth's crust corresponding to the culminating stages of the formation of the main geotectonic elements of the ancient and young platforms.

Five metallogenetic epochs are identified in the geological history of the territory of the USSR. The main commercial-genetic types of uranium deposits occurred during the course of these periods, which are as follows:

1. Early Proterozoic, 1.6 to 1.8 billion years ago (the deposits of the Krivoy Rog, Kirovograd, and Onega regions);
2. Early Paleozoic, 350 to 410 million years ago (the deposits of the Kokchetav, Balkhash, and Yenisey regions);
3. Late Paleozoic, 240 to 270 million years ago (the deposits of the Karamzarskoy region);
4. Mesozoic, 130 to 150 million years ago (the deposits of the Strelitsa and Transural regions);
5. Cenozoic, less than 20 million years ago (the deposits of the Kyzyl Kum, Caspean, and Vitim regions).

The Early Proterozoic epoch corresponded to the culminating period of protoactivation of blocks of the mature continental crust of the ancient platforms. During the course of this process, the Archean crystalline basement of the platforms broke and resulted in the formation of long deep faults. Within their zones, intensive alkaline metasomatism accompanied by uranium ore formation developed without any connection with the preceding magmatism. The metallogeny of the uranium of the Early Proterozoic epoch within the territory of the USSR is dictated by deposits in albite metasomatites (albitites).

The Early Paleozoic epoch corresponded to the orogenic period of the development of the Caledonian fold systems. The uranium metallization process of this epoch is represented primarily by hydrothermal vein-stockwork deposits in preorogenic fold and orogenic volcanic systems with the sharp predominance of the former. The appearance of the first sandstone-type deposits in the history of geology (in the Yenisey region) is also associated with this epoch. It should be noted that any uranium metallization process of this epoch is virtually unknown outside the confines of the USSR.

The Late Paleozoic epoch corresponded to the orogenic period of the development of the Hercynian fold systems. Within the territory of the USSR, this epoch of the formation of uranium deposits was manifested rather weakly, appearing exclusively in the form of vein-stockwork deposits in orogenic volcanic systems (the Karamazarskiy region).

The Late Mesozoic epoch corresponded to the intensive epiplatform orogenesis of previously stabilized blocks of the basement of the young platforms. The specified epoch was an epoch of the wide-scale appearance of uranium deposits of the vein-stockwork type in continental volcanic systems (the Strelitsa uranium ore region). Uranium deposits associated with ground-oxidation processes (the Transural region) began to form in this epoch on the peneplainized surface of ancient orogenes under platform conditions.

The Cenozoic epoch corresponds to the accumulation of the rock of the cover of the young platforms and to epiplatform orogenesis during the course of the tectonic activation of their individual regions. This epoch is characterized by a sharp decrease in the role of endogenic processes of uranium ore formation and a sharp increase in the role of exogenic processes thereof. Thick artesian basins with stable infiltration conditions formed in the regions of epiplatform orogenes deposited on segments of platform with a developed cover of permeable terrigenous sediments. This in turn caused the mass formation of sheet-infiltration uranium deposits in connection with the sheet oxidation fronts (of the sandstone type) that are widely represented within the territory of the USSR in the Kyzyl Kum uranium ore region. Deposits associated with ground-oxidation processes in valley sediments (the Vitim uranium ore region) formed in regions of continental peneplains covering the crystalline base of the platforms. Deposits of uranium-bearing osseous detritus formed in the near-shore zones of the enclosed seas (the Caspian uranium ore region).

Hydrothermal stockwork-vein deposits formed in regions of platforms subjected to tectonomagmatic activation in the Cenozoic epoch. They are known to exist both within the confines of platform blocks adjacent to the Mediterranean moving belt (the Stavropol region) and in the vicinity of the Pacific Ocean belt. The scales of such metallization processes are limited, however.

Table 3 presents the distribution of uranium reserves and resources (in the under-\$130/kg category) by the above epochs of uranium ore formation.

Table 3. Distribution of Uranium Reserves and Resources by Epoch

Epoch	Age (Billions of Years)	Proved + Additional Reserves		Forecast Resources	
		Tons	%	Tons	%
Early Proterozoic	1.8-1.6	296,000	25	70,000	14
Early Paleozoic	0.41-0.35	185,000	15	95,000	19
Late Paleozoic	0.27-0.24	34,000	3	-	-
Late Mesozoic	0.15-0.13	235,000	20	70,000	14
Cenozoic	0.02	436,000	37	265,000	53

A combined analysis of the distribution of uranium resources by age and deposit type clearly demonstrates the evolution of these types in geological history with a gradual shift in the maximum of uranium ore formation from deposits of the endogenic group to deposits of the exogenic group (Figure 26). The laws of the evolution of uranium ore formation in the earth's geological history, as discovered on the basis of a study of the deposits of the USSR,

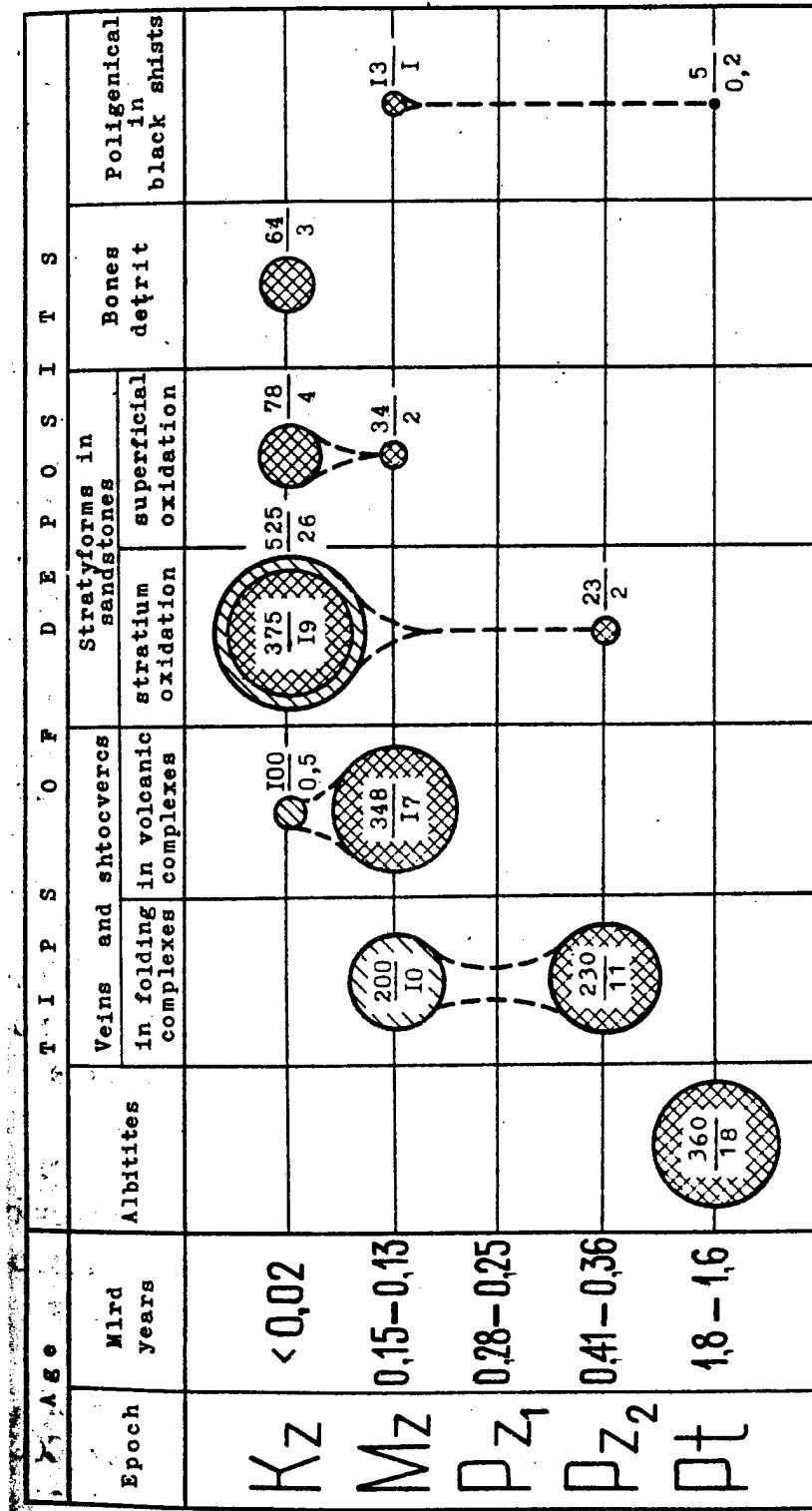


Figure 26. Diagram of the distribution of uranium resources by type of deposit and epoch of ore formation (proved, additional, and forecast reserves of all categories). The numerators of the numbers in circles indicate resources in thousands of metric tons, whereas the denominators indicate their percentages. The double links indicate the resources of already-determined regions; the single lines indicate resources of assumed new regions.

conform to the general global laws of this evolution, whose existence was first indicated by Soviet geologists. In addition, deposits of the Phanerozoic epochs of ore formation classified as being of the endogenic and exogenic types play a predominant role in the structure of the raw material base in the USSR. Deposits of the Precambrian epochs appear less often in the USSR than in other regions of the world, deposits of the ancient conglomerate type are virtually absent, and deposits of the polygenic group (including so-called unconformities) are very weakly developed.

The aforementioned difference between the structure of the uranium raw material base in the USSR and that of the rest of the world's countries is possibly linked to the fact that the discovery and exploration of ancient formations within the territory of the USSR that potentially contain uranium has been comparatively weak. It should be noted that no other similar deposits have been discovered throughout the world since the formations in the Republic of South Africa and Canada, which have been known to exist since the middle of the century.

Considering the aforementioned weak study of ancient systems and the recent discovery of deposits having some similarity with them (Padma), the discovery of "unconformity"-type deposits in the USSR may be considered rather likely.

Furthermore, the prospects of a further increase in uranium resources in the USSR may be tied above all to the commercial types of deposits that have already been determined for this portion of the planet. The hydrothermal vein-stockwork deposits in fold systems within the territory of the USSR correspond primarily to the Caledonian epoch. There is no basis to assume, however, that the corresponding types of deposits from more recent epochs (the Hercynian and especially the Mesozoic) cannot be productive. The presence in Mesozoic fold zones in the Eastern USSR of a series of masses of early stabilization that have been actively transformed by Mesozoic orogenesis (Bureya, Khanka, Omolon, the southeastern periphery of the Siberian platform, etc.), makes it possible to consider the discovery of new uranium ore regions in them rather likely.

On the other hand, a gradual decrease in age (from the Caledonian and Hercynian in the case of the Balkhash and Karamzarskiy regions to the Upper Jurassic in the case of the Strelitsa region and to the Cretaceous period in the case of the Lastochka deposit in the Bureya mass) proceeding from east to west is very evident in the case of the hydrothermal deposits associated with volcanic systems within the territory of the USSR. If one also considers the presence of similar formations of Cenozoic age in the western segment of the Pacific Ocean volcanic ring and the extensive appearance of Late Mesozoic-Cenozoic continental volcanic activity of heterogeneous composition throughout the entire region of the Soviet Far East (from Primorye to Chukotka), the prospects of the discovery of new uranium ore-bearing regions with deposits of this type may be considered quite realistic.

Finally, the wide-scale appearance of Cenozoic orogenesis in regions of young platforms in conjunction with the mountain formations of the Tyan-Shan and

Altay make it possible to consider the discovery of new uranium ore regions with infiltration-type deposits analogous to those of the Kyzyl Kum region quite realistic.

Overall, the geological prospects of the territory of the USSR with regard to the discovery of new uranium-bearing regions are rather high, and the estimates presented in connection with such regions of forecast resources may be considered very cautious.

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